Peregrinations on Cold Fusion*

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Over the past couple of months, it has become abundantly clear that the knowledge and paradigms acquired by several generations of physicists who have studied the interactions of accelerated particles are inadequate to account for the so-called "cold fusion" results claimed by the University of Utah researchers. Indeed, these results have engendered a high level of healthy skepticism in the physics community.

Now that the specter of cold fusion has again been raised,[1] I wish to list possible mechanisms worthy of investigation that might collectively substantiate what would otherwise seem to be such an ethereal prospect.

1. Screening of the deuteron Coulomb potential in a crystal lattice.

2. The tendency of bosons to condense in a crystal lattice.

3. The many-body aspects of an Avogadro number of room temperature deuterons fixed at interstitial lattice sites by a periodic potential.

4. Resonance effects in this periodic potential enhancing the transparency of the Coulomb barrier at certain deuteron energies leading to metastable states.

Although others, no doubt, have also been exploring mechanisms #1 and #2, I would like to emphasize that #4 is a mechanism that I have just stumbled upon and whose exploration I wish to encourage.

A serious research effort on cold fusion requires an interdisciplinary team of chemists and physicists (nuclear, solid-state, many-body, and plasma).

A properly hewn theory requires decent experimental data exhibiting the phenomenon of cold fusion.

1. F. Paneth and K. Peters, *Die Naturwissenschaften* **43**, 956 (1926).

A (Slightly Revised) Simple Model for Coherent DD Fusion in the Presence of a Lattice

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ABSTRACT

A highly speculative but simple model for $DD \longrightarrow {}^4He$ fusion in the presence of a lattice is proposed. Within this model, neutron and tritium reactions are supressed due to coherence, and energy extraction occurs from virtual states in which many fusions have occured. The matrix element for the coherent process is derived from electromagnetic coupling in a three-body process, in which two of the bodies are initially deuterons, and the third body is an electron (or electron coupled to a lattice).

Towards a Theoretical Understanding of Cold Fusion: Deuterium Bose Clusters in Lattice Defects.

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Our previous study of thermal equilibrium fusion rates with different parameters have lead us to conclusion that Jones-like cold fusion experiments can only be explained by non thermal equilibrium processes. Our opinion is that there are two different type of processes leading to the observed fusion rates: (i) the deuteron scattering on a deuterium Bose cluster, produced by steady state flow, leading to a steady neutron signal, (ii) the stress induced collapse of the cavity containing clustered deuterons leading to hot spots of microplasma and 'hot' fusion, giving as one of the products neutron bursts. Here we address the case (i).

We show that large 'metal like' aggregates of deuterons can exist in the lattice cavities or Schottky defects. Such droplets consist mostly of deuterons but we consider a possibility of a small number of protons to be present as well. In our model the electrons are treated statistically in a manner similar to the Thomas-Fermi description, while a deuteron condensate wave function is determined by the single particle Schrödinger equation. The deuteron-deuteron interaction (similarly deuteron-proton) is assumed to be screened by electron fluctuations. Our self-consistent calculations show that large deuteron densities can be reached within the droplet, and they are very dependent on the value of the screening parameter. Specific results of our work will be presented.

Deviations from Maxwell Velocity Distributions in Equilibrated Inhomogeneous Fluids

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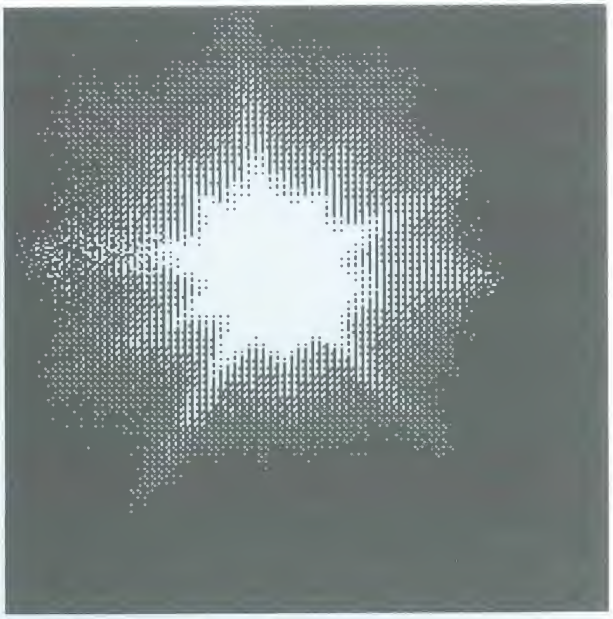
Abstract

Determining velocity distribution functions for ensembles is one of the most fundamental problems in statistical mechanics. In this paper, using computer molecular dynamics (MD) methods, we demonstrate that the velocity distribution of a classical particle subjected to a strong time-independent force field in an inertial heat bath is generally noncanonical. When the system reaches equilibrium, a non-Maxwellian distribution persists for velocity components along the field direction.

Fusion Rates for Hydrogen Isotopic Molecules of Relevance for Cold Fusion* K. SZALEWICZ, J.D. MORGAN III: U. Delaware; H.J. MONKHORST: U. Florida. — In response to the recent announcements of evidence for room-temperature fusion in the electrolysis of D_2O, we have analyzed how the fusion rate depends on several factors, including the reduced mass of the fusing nuclei and the degree of vibrational excitation. Calculations have been performed within the adiabatic approximation employing an accurate Born-Oppenheimer potential energy curve and including the adiabatic and relativistic corrections. We have also used the WKB model which displays the essence of these factors. Our results predict fusion rates for the ground vibrational states up to 14 orders of magnitude larger than previously estimated and exhibit a strong dependence of the Coulomb barrier penetration factor on the reduced mass of the pair of nucleons. We have found that fusion out of vibrationally excited states is enhanced by several orders of magnitude, which may be of particular significance in light of the experimental evidence for the importance of non-equilibrium conditions. To assist in the investigation of whether a 'heavy' electron arising from complicated collective solid-state effects could play a role in the enhanced fusion rates seen in the experiments, we study how the Coulomb barrier penetration factor depends on the mass of a hypothetical particle (or quasi-particle) of charge -1. We examine the issue of whether the excess heat observed in one of the experiments could arise from the aneutronic fusion reaction $p + d = {}^3He + \gamma$. We find that under the conditions implied by the measurements of the neutron flux from the reaction $d + d = {}^3He + n$, it is unlikely that the excess heat observed by one of the groups could arise from $p + d$ fusion.

*Supported by the Division of Advanced Energy Projects, DOE.



NEUTRON AND GAMMA-RAY SPECTROSCOPY

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We have performed an experiment similar to the one performed in Frascati by F. Scaramuzzi et al. with the intention of ascertaining their results relative to neutron emission from a Titanium-Deuterium system. Deuterium was absorbed into 2 g of Titanium dust placed in a 3 cm^3 cylindrical inox receptacle which was then subjected to thermal shocks by dipping it in liquid Nitrogen, liquid Helium, and the application of heat pulses. Neutron emission detection was attempted.

Titanium dust treated in the usual manner, i.e. heating in vacuum for 14 hours at 900 C, was placed in the inox receptacle and air was evacuated before injecting Deuterium at an initial pressure of 150 bar. The receptacle was then heated to 500 C for 8 hours (in order to increase the absorption rate) and cooled down slowly to ambient temperature. About 0.08 g of Deuterium were absorbed (4%).

Several experiments using different methods to cool the receptacle were performed: a) sudden lowering of the temperature to 77 K; b) sudden lowering in two stages (to 77 K and then to 4.2 K) followed by application of heat pulses by means of an heating winding; and c) sudden lowering of the temperature to 77 K followed by an evacuation of the receptacle. All these runs were at least 20 hours long and in none of them any significant neutron emission above background (1-2 counts per hour) level was detected.

Nuclear Measurements for Cold-Fusion Experiments. R. E. Anderson, R. D. Bolton, K. B. Butterfield, C. A. Goulding, M. W. Johnson, and E. M. Leonard, Los Alamos National Laboratory, Los Alamos, NM 87545. A wide range of nuclear measurements have been performed in support of cold-fusion experiments at Los Alamos, including high- and low-resolution gamma-ray spectroscopy; integral neutron counting with well detectors and banks of ^{3}He tubes; and neutron spectroscopy with NE-213 scintillators. Experiments included automated data acquisition for all measurement techniques. Results, including data both from electrochemical cells and background measurements, will be presented for all techniques. A discussion of sources of background neutron and gamma-ray events will also be presented, focusing on certain less usual sources of background (such as 2.223-MeV gamma rays resulting from interaction of background neutrons with hydrogen in the large neutron well counters), and on diurnal and other predictable variations in background counting rates.

SEARCH FOR COLD FUSION IN PLASMA-CHARGED Pd-D AND Ti-D SYSTEMS

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ABSTRACT

To investigate whether cold fusion of deuterium (D) can occur in solid Pd and Ti as proposed recently, we have searched for the D-D fusion reaction in plasma-charged Pd-D and Ti-D. A DC glow-discharge was established in a deuterium gas (pressure 1-5 torr) between two water-cooled electrodes in a small reaction cell. The Pd or Ti sample was placed on the cathode, and the DC voltage across the plasma varied between 200 and 400 V. A thin (100 Å) Cu film was evaporated on the Pd samples to establish a barrier preventing the escape of D from the Pd samples. Various Pd samples were investigated, an evaporated 1 μm thick Pd foil, a commercial, cold-worked 25 μm thick Pd foil, and Pd single crystals.

Neutrons were detected with an NE213 liquid scintillator (5" diameter and 2" thick, intrinsic efficiency 20%). The conventional pulse-shape discrimination technique was employed to separate gamma counts from neutron counts. The detection efficiency for neutrons in the sample geometry was 3%, as determined with an AmBe neutron source. In the energy spectrum, the interest was focussed on the region where the 2.5 MeV neutrons from the D-D reaction was expected. In the laboratory two floors below ground level, the background counting rate in the neutron window was about 0.01 counts/sec.

The samples were charged with deuterium during the measurements, which continued for periods up to two weeks. No indication of a neutron count rate in excess of the natural background level was observed.

In parallel, we tried to reproduce the electrolytical-charging experiment of Pons and Fleischmann with a Pd single crystal (approximately 0.2 cm^3), a Pt anode, and a solution of 0.1 M LiOD in D_2O (99.5% pure). Again, the observed neutron count rate did not deviate from the background level.

Measurements of Gamma-Ray Spectra and Neutron Fluxes in Pons' Laboratory at the University of Utah

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We present results of gamma ray spectroscopy and flux measurements of fast and thermal neutrons performed near an operating Pd-D2O cell in Pons' laboratory at the University of Utah. Gamma ray spectra were collected with an 8" diam x 4" NaI:Tl crystal, of resolution ~ 10%/sqrt(E). Both fast and thermal neutron fluxes were measured using plastic nuclear track detectors (Cronar and Lexan) sandwiched around foils of enriched U-235 (the plastic films detect neutron-induced fission fragments); half of these were shielded by Cd to provide separate fast and thermal neutron data. An independent measure of the combined fast and thermal neutron flux has been obtained from an activation analysis using In-115 foils, counted on a 50 cc intrinsic Ge detector. Finally, we describe a neutron spectrometer (BC501 liquid scintillator with pulse shape discrimination) that will shortly be operating in Pons' lab.

A Neutron Coincidence Calorimeter

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and Gary L. Jensen, Brigham Young Univ., Provo, Utah

Abstract: We have developed a spectrometer for MeV neutrons that relies upon total energy absorption to measure neutron energy. A coincidence signal is required from the capture of thermalized neutrons in Li-6 glass scintillators incorporated in the detector body. This dual signal from a single neutron provides a powerful means of discrimination against background events arising either from gamma rays or from ambient, low-energy neutrons. The spectrometer is particularly useful in situations in which the neutron source intensity is very low.

A Search for Neutrons From Fusion in a Highly Deuterated Cooled Palladium Thin Film

by

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We have carried out an experiment to search for neutrons released from a thin film of Pd-10%Ir. A film of thickness ≈2000Åwas prepared by sputtering. The film was then cooled to 77K, and was charged with deuterons by low-energy ion implantation, to a stochiometry of approximately PdD_5. Deuterium was incident on the film as neutral D and D_2 with a kinetic energy of 1000 eV. Paraffin was used as a neutron moderator and absorber, with a NaI detector to observe the 2.22-MeV γ-ray expected from neutron capture by hydrogen nuclei.

We observed fewer than 25 2.226-MeV gamma rays over a period of one hours, corresponding to a limit of fewer than 35 neutrons produced per second, from the 10^{21} deuterons in the film. We also place a limit during this period of fewer than ten 23.8-MeV γ-rays (from fusion producing ^{4}He). Our limit on neutron production is well above the rate observed in electrolysis experiments. The high deuteron density and high implantation energy might however have produced an elevated rate of fusion in our sample. Evidently this did not occur.

Neutrons from Cold Fusion?

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At the Niels Bohr Institute in Copenhagen we have set up sensitive neutron detection equipment to look at electrolysis cells after the prescription of Jones and of Pons and Fleischmann. The neutron detectors are two 3 l liquid scintillator detectors with pulseshape discrimination. Our sensitivity is about a factor of 10 better than Jones but until now at this sensitivity our result is zero. We are now also investigating the titanium deuterium gas system described by the ENEA group at Frascati, Italy. Other experiments in Denmark will be mentioned.

ABSTRACT

High-Sensitivity Neutron Detectors Used at Sandia Laboratories to Monitor Cold Fusion Cells, by Ronald I. Ewing, Sandia National Laboratories, Albuquerque, New Mexico.

High-sensitivity neutron detectors have been set up adjacent to several cold fusion experiments at Sandia since April 14, and none of the detectors has indicated any neutron emission above normal background levels. The detectors consist of eleven helium-3 thermal neutron detection tubes imbedded in a polyethylene moderator slab covered with cadmium. Each detector was calibrated in situ by placing a californium-252 neutron source of known intensity at the location of the test cells. The detectors are sufficiently sensitive that a source of fusion neutrons emitting 10 neutrons per second (corresponding to a fusion energy release rate of about 10^{-11} watts) would produce a 25 percent increase over the background counting rate, which is 2 counts per second. These detectors are several thousand times as sensitive to fusion neutrons as the "Bonner sphere" neutron dosimeters, and are capable of neutron energy discrimination using ratio techniques. The detectors indicate a small diurnal variation ($\pm$4%) due to the variation of the cosmic-ray induced background, and have detected the presence of people working around the cells due to the neutron attenuation of the human body. Several other detectors are also being considered for use in these studies.

EXPERIMENTS IN INC DIVISION AT LOS ALAMOS RELATED TO COLD FUSION

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In INC-Division at Los Alamos, we have considered several experiments aimed mainly at verification that electrochemically induced nuclear processes can actually occur. We felt, from the onset, that the most convincing signal for nuclear processes would be the production of neutrons and have taken on the task of designing and executing several experiments to detect neutrons.

Several electrochemical experiments have been run using electrodes of Ti and Pd. Both normal and precharged electrodes have been investigated. To date these experiments have all yielded negative results for the emission of neutrons or Pd X-rays. No heat measurements have been made on these cells.

Since the fusion rate reported by Jones at BYU is very low, we felt one way to improve the chances for unambiguous detection would be to switch to the D-T fusion system and we have run one experiment in which we used a Ti cathode that was precharged with tritium. Again, there has been no emission of neutrons.

In view of the recent results from groups in Italy who have reported the emission of neutrons from systems containing Ti and deuterium, we have initiated a series of experiments to verify those results. In these experiments, we have observed a number of anomalous counting events and now feel that we have observed some emission of neutrons from these experiments.

EXPLORATION OF THE POSSIBILITY OF STRAIN OR FRACTURING PROCESSES AS A MECHANISM FOR NUCLEAR FUSION IN METAL DEUTERIDES

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AND

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A series of experiments has been carried out with titanium metal in contact with various pressures of D_2 gas or prepared titanium deuteride in which the samples have been thermally cycled and observed for neutron emission. For the series of experiments with titanium metal in contact with D_2 gas, several forms of Ti were investigated including sponge, sponge crystals, metal turnings, porous Ti previously used as an electrode in a Jones-type electrochemical cell, and small pieces of sheet metal; gas pressures ranged between 6 and 100 atm. Thermal cycling was carried out between LN and room temperature, in most cases. Correlated neutron emission bursts have been observed on four occasions, during the warming cycle, for two different samples containing mixes of metal types. Experiments in which samples were heated above the phase boundary at 300° C have also been performed. Metal samples deuterided at 550 °C have been examined under similar conditions.

Experiments are currently underway at WSU in which predeuterided Ti samples are subjected to mechanical stress and examined for particle emission. To date, both negative and positive particle emission have been detected accompanying and following fracture, indicating non-metallic excitation of several eV energy and very likely the occurrence of charge separation across the fracture. A series of gas gun experiments, in which TiD_x will be fractured and examined for tribo-luminescence and neutron emission, is in an early stage of development.

The nature of the neutron emission is consistent with a fracturing or strain mechanism that could conceivable result in either cold or hot fusion.

Cold Fusion Neutron Measurements at ORNL. D.P. HUTCHINSON, R.K. RICHARDS, C.A. BENNETT, C.C. HAVENER, C.H. MA, F.G. PEREY, R.R. SPENCER, J.K. DICKENS, B.D. ROONEY, ORNL,* J. BULLOCK IV, and G.L. POWELL, Y-12 Development–A number of experiments were begun on 29 March 1989 to look for neutron emission from a palladium cathode in an electrolytic cell using a deuterated electrolyte. Several different electrode configurations were tried. The fast neutron detector utilized a pair of NE213 scintillator/photomultiplier pairs in a shielded enclosure. This neutron detector has an efficiency of 13% and records a background count rate of 200 events per hour. At present no neutron counts above the background level have been detected.

*Operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract No. DE-AC05-84OR21400.

NEUTRON/GAMMA-RAY IMAGING OF FUSION SOURCES

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Established techniques for imaging intense nuclear fission and fusion sources via the emitted or related neutrons and gamma rays could be adapted for less intense (but longer temporal duration) fusion sources. The relaxation of temporal resolution requirements from the nanosecond or millisecond regime to the kilosecond regime may allow spatially-resolved imaging of a cold fusion source emitting ~10^4 n/s for one hour. Additionally, one would anticipate that d-t reactions at a comparable fusion rate as the reported[1] d-d rate would generate several orders of magnitude more neutrons so that smaller temporal and spatial samples could be utilized.

Key components of the system would be a thick pinslit aperture or a multi-channel collimator, a sensitive inorganic radiation converter screen, a peltier-cooled charge-coupled device (CCD) video camera, and a microcomputer-based data acquisition system. The newly developed camera has such low thermal noise that data can be integrated on the CCD sensor for up to 90 minutes. Directional information could confirm that the "cold fusion cell" is the source of the ionizing radiation. Also, if source strengths were sufficient, identification of the location within the cell or along the Pd rod axis might eventually be possible. Such information may be useful in monitoring larger-scale devices and for safety aspects. The imaging technique would be complemented by an energy-resolving neutron detector located just behind the converter screen. Lead and borated-paraffin absorbers could be used to strongly attenuate low-energy x rays and thermal neutrons, respectively, at the entrance of the aperture.

Samples of previous nuclear radiation source images and the scaling to less intense sources will be presented.

Reference

1. M. Fleischmann, S. Pons, and M. Hawkins "Electrochemically Induced Nuclear Fusion of Deuterium," J. Electronanal. Chem. 261, p. 301-308, (1989).

SEARCH FOR NEUTRONS, GAMMA-RAYS, PROTONS, BETA-PARTICLES, X-RAYS, TRITIUM ASSOCIATED WITH COLD FUSION IN DEUTERIDED METALS*

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In a search for cold fusion of hydrogen isotopes in electrolytically deuterided metals, no significant statistical deviation of either neutron, proton, beta-particle, x-ray, or gamma-ray emission above the background have been observed. By suppressing the background with shielding and cosmic ray veto counters, the rate of cold fusion of d+d has been measured to be less than that which would correspond to the measured background which is at a level of less than 10^{-25} fusions/atom pair/sec (1), a factor of approximately 100 below the yield reported by Jones et al. It has also been determined that the occurrence of cold fusion of p+d, which has recently been estimated to be eight orders of magnitude larger than the d+d reaction, does not exceed 10^{-22} fusions/atom pair/sec in our electrolytic cells.

The detection of fast neutrons was achieved with an array of six liquid scintillation counters (~1% efficient) (Yale-BNL collaboration), as well as an array of 24 BF_3 counters (~14% efficient) at BNL. All systems were well shielded from background and utilized cosmic ray veto detectors. Cosmic rays have been observed to produce neutrons. A Si surface barrier detector was used to detect energetic charged particles and x-rays. The gamma rays were detected with a 12.5 cm NaI(Tl) detectors. Electrolytic cells employing Pd or Ti cathodes in the form of thick rods or foils were used in electrolytes based on those used in previously reported experiments by Jones et al. and Fleischmann, Pons, and Hawkins. The Pd electrodes were cold worked or annealed in vacuum or argon, one electrode was predeuterided, and various surface treatments were carried out. The metals were electrochemically charged with deuterium from heavy water electrolytes (97.5% or 99.8% D_2O) containing LiOD or a variety of dissolved salts. The null results were obtained for specific individual runs utilizing various systems alternating between cells on and off during the period of more than a month. Other measurements of tritium, heat and surface conditions will be shown.

*Work performed in collaboration with H. S. Isaacs, A. J. Davenport, H. Wiesmann, M. Weber, J. Hurst, J. J. Reilly, and M. Zucker at Brookhaven National Laboratory, Upton, NY 11973 and M. Gai, S. L. Rugari, R. H. France, B. J. Lund, and Z. Zhao, A. W. Wright Nuclear Structure Laboratory, Yale University, New Haven, CT 06511.

Work supported in part by US DOE under Contract Nos. DE-AC02-76ER03074 and DE-AC02-76CH00016.

1. M. Gai, S. L. Rugari, R. H. France, B. J. Lund, and Z. Zhao, A. J. Davenport, H. S. Isaacs, and K. G. Lynn, presented at Am. Phys. Soc. Spring Meeting, Baltimore, May 1989.

Search for neutron and gamma-ray emission from the cold fusion

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Emission of neutrons and γ rays was measured under the various electro-chemical conditions. A pair of 8" diameter liquid scintillators (NE213) were used for the detection. Pulse shape discrimination was applied to identify neutrons and γ rays. Radiation shield of combination of poli-ethylene, iron, and lead combined with the veto counters made of plastic scintillators provided a very low backgorund condition. So far no sign of the neutron emission associated with cold fusion has been observed in $\sim 3 \times 10^{-3}$ /s. More accumulation of the data with different conditions is underway.

The measurement of the contents of d, ^{3}He, and ^{4}He in the paradium electrode after the electro-chemical reaction is also under way. The electrode is irradiated by 1.8 MeV/nucleon beam of Ar and recoil particles are detected by a solid state detector. The pulse height and the time of flight are used for identification of the particle.

More Searches for Cold Fusion * E. B. Norman, B. Sur, K. T. Lesko, R. A. Henderson, K.R. Czerwinski, H. L. Hall, and D. C. Hoffman, Lawrence Berkeley Laboratory -- Following the reported observations of nuclear fusion reactions of deuterium nuclei loaded into metallic crystalline lattices[1,2], we have searched for neutrons and gamma rays that should be produced by such processes. Two types of D_2O cells containing electrodes and electrolytes similar to those described in Refs. 1 and 2 have been operated over a period of five weeks. Fast neutrons have been searched for using liquid scintillators and dosimetry film. Prompt gamma rays have been searched for using NaI detectors; induced radioactivity in the electrodes was searched for using Ge detectors. Background measurements have been conducted with the D_2O cells turned off and with an operating H_2O cell. Measurements of the masses of palladium electrodes before and after electrolysis showed that the number of deuterium atoms loaded was greater than 0.5 per Pd atom. No excess of neutrons or gamma rays above background has been observed in any of our experiments. From the neutron measurements we have established an upper limit of 2.1×10^{-24} [$d+d \rightarrow {}^3He + n$] reactions per second per deuteron occurring in our Pd electrode. Similarly the lack of 23.8-MeV gamma rays allows us to establish an upper limit of 2.7×10^{-24} [$d+d \rightarrow {}^4He + \gamma$] reactions per second per deuteron in the same electrode. In some runs, a small (15%) amount of H_2O was added to the D_2O to allow us to search for the $d + p \rightarrow {}^3He + \gamma$ reaction. No excess of 5.5-MeV gamma rays above background was observed and an upper limit of 1.8×10^{-23} such reactions per proton per second in our Pd electrode was established.

* Supported by the U.S. Dept. of Energy under Contract No. DE-AC03-76SF00098.

1. M. Fleischmann and S. Pons, preprint
2. S. E. Jones et. al., preprint

NEUTRON SOURCES AND SPECTRA FROM COLD FUSION

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ABSTRACT

Recent reports of heat and neutron production occurring in metal electrodes in a deuterium oxide bath have resulted in speculation that a fusion reaction is occurring at low temperatures. The candidates for the fusion reactions occurring are:

$$D + D = {}^4He,$$

$$D + D = T + H,$$

$$D + D = {}^3He + n,$$

and a possible secondary fusion reaction is:

$$T + D = {}^4He + n.$$

Each of these reactions produce neutrons and/or charged particles.

The primary neutrons form one of the many possible candidates for a signature for the fusion reaction. These neutrons themselves, as they thermalize, are captured in the surrounding material producing a gamma source, which will be transported throughout the reaction vessel. The gamma source if energetic enough, will undergo (gamma,n) reactions, primarily in the deuterium, resulting in a secondary neutron source. The charged particles may also undergo neutron-producing reactions. These neutron spectra may be used to indicate that a fusion reaction has indeed occurred.

This paper investigates these possible neutron producing reactions, and for those most likely occurring reactions, source strength and spectra are calculated. The charged-particle induced neutron spectra and source strengths are calculated with the SOURCES code. The (gamma,n) neutron source spectum is determined using the PHONEX code. The neutron flux spectrum is determined from transport calculations with ONEDANT.

Typical of the results is the neutron energy flux spectrum shown in Figure 1. These results represent the neutron energy flux found one centimeter from the edge of a 6.0 cm diameter flask with 0.5 cm glass wall. The neutron source is one neutron/cm-second distributed evenly within a 0.4 cm diameter titanium rod at the center of the cell. The source neutron energy is 2.45 MeV. Figure 1 thus represents the neutron flux spectrum from the familiar DD fusion neutron source.

γ-Ray Spectra in the Fleischmann, Pons, Hawkins Experiment

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Abstract

Fleischmann, Pons, and Hawkins (FPH)[1,2] recently announced that significant fusion heating was occurring in their cold fusion experiments. As compelling evidence of fusion processes, they reported the detection of 2.2 MeV γ rays that result from neutron-capture-on-hydrogen.

We have carefully analyzed the published γ-ray spectra of FPH. We have also performed detailed terrestrial γ background measurements and neutron-capture-on-hydrogen experiments. From our analyses we conclude that the FPH γ line is specious on the basis of three quantitative considerations: (1) it has a line width a factor of 2 smaller than the detector instrumental resolution would allow at 2.2 MeV; (2) there is no evidence of a Compton edge at 1.99 MeV (i.e., 2.22 MeV - 0.23 MeV), and this edge should be distinctly prominent; and (3) FPH's estimate of the neutron source rate, based on their purported γ signal, is a factor of 50 too large. Additionally, from terrestrial γ background considerations, we argue that FPH's γ "line" actually resides at 2.5 MeV rather than 2.2 MeV. Based on these arguments, we conclude that the γ signal of FPH cannot be the 2.2 MeV neutron-capture-on-hydrogen γ ray. We can offer no plausible explanation for the feature, other than it is possibly an instrumental artifact unrelated to a γ-ray interaction.

COLD FUSION REACTION PRODUCTS AND THEIR MEASUREMENT

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ABSTRACT

The major reaction products that have been associated with cold fusion reactions are: neutrons, protons, tritium, He-4, He-3, internal conversion electrons, and gamma radiation. The branching ratios and relative reaction rates for these products are examined for consistency with cold fusion experiments. Both theoretical calculations and experimental data are examined and will be presented. For example, the He-4 plus internal conversion has been proposed in order to explain the absence of neutrons or gamma radiation. This reaction is not favored, even in a deuterium-palladium system. In the event this reaction occurs, deexcitation of the excited He-4 nucleus would predominantly occur by gamma emission. Even if internal conversion dominates, considerable Bremmsstrahlung radiation would be generated. Either the Bremmsstrahlung or the gamma radiation would also create neutrons from the photodisintegration of deuterium. Measurement of these reaction products must be made carefully owing to their presence in background. For example, the 2.2 MeV gamma ray from Bi-214, background tritium in the heavy water, and neutrons from the photodisintegration of the deuterium from background radiation. These problems will be discussed and experimentally obtained examples will be presented.

SEARCH FOR COLD-FUSION NEUTRONS IN HIGH PRESSURE D_2 LOADED Ti and Pd*

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Sandia National Laboratories
Albuquerque, NM 87185

Because of the reported observation by Prof. F. Scaramuzzi of Frascati of neutrons from cold fusion during the loading and unloading of Ti with D_2 as a function of temperature, we have subjected Ti and Pd powders to D_2 pressures up to 4 kbars while cycling temperature between room temperature and 77K. This process was continuously monitored with fast neutron detectors capable of detecting the generation of as few as 5 neutrons/sec. The detectors are He^3 tubes embedded in a polyethylene moderator and shielded by a Cd thermal neutron absorber. Thus, they are sensitive only to fast neutrons. Measurements were made in 10 minute intervals during all phases of the experiment. Previous work on pressure charging of PdD_x under similar conditions resulted in x values in excess of 0.9. X-ray analysis of the recovered Ti powder indicated no discernible TiD_x formation with this high pressure cycling. No neutrons in excess of background were detected during any of these experiments.

*This work performed at Sandia National Laboratories was supported by the U.S. Department of Energy under contract #DE-AC04-76DP00789.

NEUTRON PRODUCTION BY PHOTODISINTEGRATION OF DEUTERIUM

by

R. A. Sigg

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Savannah River Site
Aiken, SC 29808

ABSTRACT

Low-level neutron measurements require great care to account for variability in background sources. Measurements taken near deuterium for cold fusion studies must also consider another source. Photodisintegration of deuterium produces neutrons at significant rates if minerals near the measurement area contain high thorium levels.

The highest energy natural decay gamma-ray normally seen in a background spectrum is at 2614 keV. This line is from decay of Tl-208 in the Th-228 decay chain. Its energy is well above the 2223 keV threshold for the D(γ,n)H reaction. Consider that:

- Uranium and Thorium are widely dispersed in nature.
- Uranium and Thorium are commonly found in the Mountain States.
- Some building materials in the Mountain States have incorporated old uranium mine tailings.

Although Pons and Fleischmann did not report their background at 2614 keV, the gamma-ray flux may be significant.

The information contained in this abstract was developed during the course of work under Contract No. DE-AC09-76SR00001 (now Contract No. DE-AC09-88SR18035) with the U. S. Department of Energy.

Cold Fusion Experiment at Department of Nuclear Engineering, National Tsing–Hua University

Department of Nuclear Engineering (Represented by Tsang–Lang Lin), National Tsing–Hua University, Hsin–Chu, Taiwan 30043, ROC.

ABSTRACT

We are repeating the so called cold fusion experiment by electrolysing heavy water with palladium rod as the cathode and platinum wire as the anode. The purpose of our experiment is to detect the neutrons that are produced from fusion process of deuterium if fusion does occur. We use one ^3He detector and one BF_3 detector to detect the thermal neutrons coming out of the 5 cm water bath that surrounds the heavy water cell. So far, we find that neutron counts are only slightly above background. Detail results will be presented in the workshop.

Measurements of Nuclear Radiation Due to Pd-Deuterium Interactions

J. F. Wacker, R.P. Allen, R.L. Brodzinski, J.R. Divine, K.H. Pool

Battelle Pacific Northwest Laboratories, PO Box 999, Richland, WA 99352

Experiments have been run to verify the claim of Pons-Fleischmann that "cold" fusion occurs in the Pd-deuterium system. Pd cathodes were electrochemically charged with deuterium from a 0.1M LiOD electrolyte. The Pd was 99.9% pure and consisted of 3 to 5 mm wide strips cut from 25 by 25 mm wide by 1 mm thick foil piece. A Pt lead was spot-welded onto each Pd strip. Pt wire (0.68mm diameter) was used as the anode in most experiments. The LiOD solution was made by dissolving either ^{7}Li metal or $^{6}Li_2O$ in 99.8% D_2O. Cells were run at constant current, with current densities on the Pd ranging from 16 to 320 mA/cm^2; both cell voltages and currents were periodically measured, however, no temperature measurements were made. In one experimental setup, an electrochemical cell was placed inside a high sensitivity neutron counter and neutron counts were taken at 10 min intervals. In addition, temporal multiplicity events, characteristic of bursts postulated to be produced by muon catalysis, were measured by connecting the output of the neutron counter to a multiplicity counter. In a second setup, a cell was placed inside a germanium gamma-ray spectrometer to measure Pd x-rays generated by high energy fusion products (*e.g.*, protons) and secondary gammas produced by (n,γ) reactions on Cd foil placed around the electrolysis cell. Gamma-ray spectra were collected over 1 to 2 day intervals.

Approximately 10 experiments have been run to date, with the longest continuous charging time being 20 days. No positive results have been observed; upper limits to the D-D fusion reaction rate are $\sim 2 \times 10^{-21}$ and $\sim 3 \times 10^{-16}$ fusions/sec per D-D pair for neutron and x-ray measurements, respectively. Experiments are continuing and plans have been made to analyze the abundance and isotopic composition of helium in our Pd electrodes.

COLD NUCLEAR FUSION STUDIES WITH THE LAMPF BGO DETECTOR

M. Paciotti, L. Atencio, J. Cohen, R. Maltrud, A. Mayer, J. McGill, C. Morris

LOS ALAMOS NATIONAL LABORATORY
Los Alamos, New Mexico, U. S. A. 87545

S. Jones, J. Maxwell, D. Mince, S. Taylor

BRIGHAM YOUNG UNIVERSITY
Provo, Utah, U. S. A. 84604

We are exploring cold nuclear fusion using a large solid-angle detector at the Los Alamos Meson Physics Facility. The detector consists of 26 segments of bismuth germanate (BGO). Each segment is 56 mm thick with a 3-mm-thick piece of plastic scintillator bonded to its front face in a reverse phoswich arrangement. This design allows both energy and ΔE information to be extracted from each crystal for charged-particle identification and for neutral-particle separation. The detector is well-suited for gamma identification; neutron detection is enhanced by placing a polyethylene moderator/absorber around the test cell. The detector covers about 80% of 4π and permits insertion of either an electrolytic cell or a test cylinder holding metal fragments in a pressurized hydrogen + deuterium environment for cold fusion studies <see Ref. 1>.

A principal goal of the experiments is to determine the yields of 5.4 MeV gamma rays from proton-deuteron fusion relative to 2.5 MeV neutron yields from deuteron-deuteron fusion. The relative yields will be of value in assessing whether the fusion occurs due to piezonuclear fusion <2> or to 'microscopic hot fusion' accompanying strong electric fields at propagating cracks in the hydride <3>. Early results will be presented at the workshop.

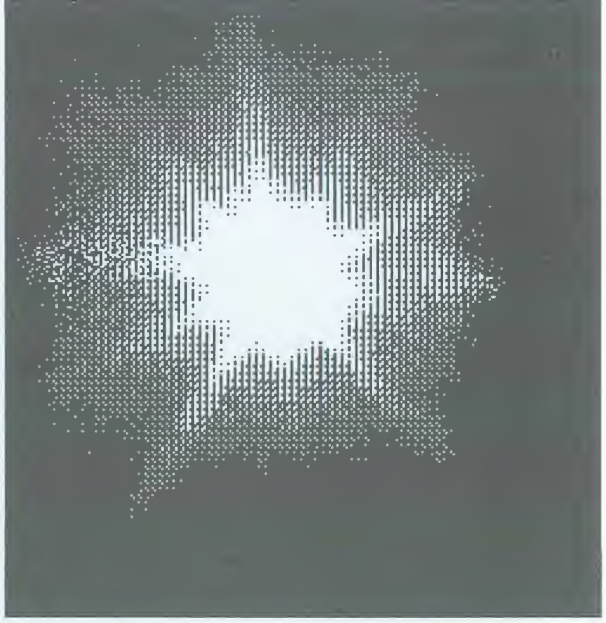
This research is supported in part by the Advanced Energy Projects Division of the U.S. Department of Energy.

<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," Nature, 338: 737-740 (April 27, 1989).

<2> C. DeW. Van Siclen and S. E. Jones, "Piezonuclear fusion in isotopic hydrogen molecules," J. Physics G12: 213-220 (March 1986).

<3> J. S. Cohen and J. D. Davies, "The cold fusion family," Nature 338: 705-707 (April 27, 1989).

SEARCH FOR D(P,GAMMA)^{3}HE COLD FUSION PROCESS. S.A. Wender, D.L. Wark, G.L. Morgan, C. Laymon and P.W. Lisowski, Los Alamos National Laboratory--It is now well established theoretically that at low temperatures the fusion rate in a plasma for the three primary fusion reactions is reversed from the order in the keV range. Koonin and Nauenberg in a recent paper submitted to "Nature" calculate a rate for the D(p,gamma)^{3}He reaction which is more than eight orders of magnitude larger than the rate for the D(d,n)^{3}He rate. If these enhancements should hold for the solid state, then even at the low level claimed for cold fusion by the BYU group, the effect would be readily detectable. A cell has been constructed containing 0.1 M LiOD and LiOH in a 3:1 ratio with Pt and Pd electrodes. The Pd was treated in a 3:1 D:H atmosphere prior to starting the electrochemistry. Detectors consisted of a 3" by 3" BGO gamma ray detector in an active cosmic ray shield and a 4" by 2" NE-213 liquid scintillator neutron detector with PSD gamma ray rejection. During the first week-long running period no neutrons or gamma rays were detected above background. Several changes in the experiment are under way which will significantly increase the sensitivity.



CALORIMETRY

Calorimetric, Neutron, Helium, and Impedance Measurements to Detect Electrochemically Induced Cold Fusion

W.Ayers and M. Dean
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P.O. Box 160
Princeton, NJ 08542

D.Manos, H.Hsuan, T.Saito, J.Timberlake, and E.Nieschmidt*
Princeton University Plasma Physics Laboratory
Princeton, NJ 08543

ABSTRACT

Cast, and cast/drawn palladium samples from 1.0 to 6.25 mm diameter and 10 cm in length were electrochemically loaded with deuterium or hydrogen from solutions 1.0 M LiOD/D2O or LiOH/H2O at constant current densities up to 620 ma/cm^2 in an attempt to duplicate the Pons-Fleischmann experiments (1).
Calorimetric measurements of heavy and light water samples were performed as a function of time, current density, and sample preparation. The cell heat transfer coefficients were measured as well as calculated from Nusselt relations for convective heat transfer. These calculations demonstrate errors in the heat transfer analysis of the CalTech group. No continuous excess enthalpy was detected in the samples. Temperature transients in the samples will be discussed in terms of possible chemical sources including the formation of peroxides at the cathode.

Neutron measurements of the samples with a reaction pulse height analysis detectors is reported in a companion report (1). No neutron were detected beyond the background level which ranged from 3 to 30 counts/hr.

The palladium samples were analyzed for lithium and helium. Helium content was initially analyzed by spark gap spectroscopy. This technique could not resolve 4^He from 12^C^+3. Sample analysis by high resolution mass spectrometry is underway (3). Lithium was not detected below the roughened surface (~1 micron).

Impedance changes in the palladium samples during charging with hydrogen or deuterium provide clear indication of sample saturation and diffusion times. These data indicate that anomalous (non-equilibrium) hydrogen or deuterium concentrations are reached within the samples when the current is lowered or reversed. The impedance measurements detected no internal consumption of deuterium/deuteron species.

* Idaho National Laboratory, Idaho Falls, Idaho

1. Fleischmann,M. and Pons,S., J. Electroanal. Chem. 26, 301-308 (1989).
2. H. Hsuan et. al. Princeton University Plasma Physics Laboratory Abstract Santa Fe Workshop on Cold Fusion.
3. Analysis by Rockwell International Inc.

Calorimetry Cell Design for Cold Fusion Studies. D.P. HUTCHINSON, C.A. BENNETT, R.K. RICHARDS, ORNL,* J. BULLOCK IV, and G.L. POWELL, Y-12 Development--Several calorimetry cells have been constructed for the measurement of heat output from electrolysis cells containing palladium rod cathodes. The cells have been calibrated using a resistance heater and a bank of independently calibrated thermistors. The cells are immersed in a 15°C constant temperature bath. Several cells are being operated with palladium cathodes prepared by extrusion and cast techniques. The minimum level of observable excess joule heating power for the cells is estimated to be 1.5% of the applied power to the cell. Data will be presented on the cell design and calibration and the results of the measurements to date will be given.

*Operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract No. DE-AC05-84OR21400.

CALORIMETRY OF "COLD FUSION" CELLS

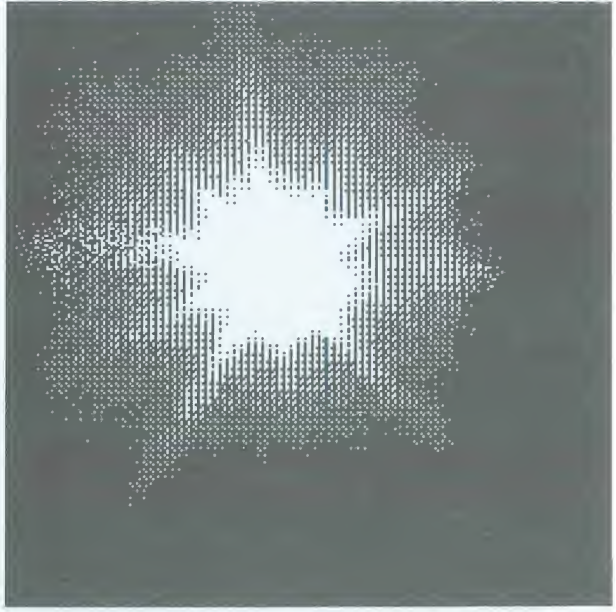
This paper presents results of an investigation of "cold fusion". Test cells were assembled that are essentially identical, except that one has H_2O and the other has D_2O. Each cell has both electrodes of nickel wire. These are connected to variable voltage, 60 Hz. power supplies. The water in each cell has a volume of 6 cc, to which is added one cc of LiCl having one gram of LiCl per 10^4 cc of water. The temperature rise of each cell, cooled by ambient air, was measured for known amounts of electric power input. A difference in cell temperatures, for the same power input, would reveal a source of power originating in the cell having the higher temperature. A temperature increase of 2° C corresponds to 0.1 watt input. The thermometers are accurate within ±0.5°, and were calibrated in a water bath.

Two runs showed an "excess power" of 20%. Two subsequent runs showed no "excess power." Each run was started with completely new cells. Three runs with no LiCl present showed no "excess power."

RE: Calorimetric and Thermodynamic Investigation of the Electrolysis of LiOD Solutions with Palladium Cathodes

Bruce E. Gammon *, Charles R. Martin -, Kenneth N. Marsh *
Texas A&M University
* Thermodynamics Research Center
- Department of Chemistry
College Station, TX 77831-3111

Possible sources of errors in calorimetric measurements will be described. The thermodynamic and thermophysical implications of charging a palladium electrode with isotopes of hydrogen will be discussed. A calorimetric measuring system devised at Texas A&M University for testing for excess power will be described. It employs a power-compensation heat-conduction principle and provides for stirring of the electrolyte. Provisions for metering and analysis of effluent gases and for replenishing their parent materials will be outlined. Provisions for analysis of the electrode materials and solutions will also be discussed. Results obtained will be discussed.



ANALYTICAL CHEMISTRY OF APPROPRIATE PRODUCTS

VISIBLE PHOTON YIELDS IN Pd/D_2O ELECTROLYSIS*

H. G. Berry, C. Kurtz, M. L. A. Raphaelian,† and G. J. Perlow
Physics Division, Argonne National Laboratory, Argonne IL 60439

We have investigated the light emitted from the active side of a palladium cathode in an electrolytic cell. The experiment was designed to search for very low yields of light emission, expected to occur in any energy exchanges from a cold fusion process. The electrolyte is 1.5 M HNO_3 in D_2O. Experiments were also performed including LiOH in heavy and light water. The anode is platinum. The cell is contained in a light tight box and the cathode is viewed by a cooled photomultiplier. Observations were made in the wavelength range 3000 to 8500 Å.

Results to date are as follows:

Photon yields of 1 to 20 per second are obtained in observations covering the wavelength range of 3000 to 8500 Å.

The observed rates correspond to 1 to 20 photons per 10^{17} charge carriers in the cell. The yields vary with time, temperature, and current. Using different filters within the above wavelength range, we verify:

1) Infrared photon yields (above 7000 Å) depend partially on the electrolyte temperature
2) At wavelengths below 6000 Å, the major dependence is on power input to the cell.
3) No significant yield from the Balmer α, $n = 2\text{-}3$, transition in deuterium is observed.
4) Fluorescence continues at a reduced rate (1 to 3 photons per second observed) when current to the cell is reduced to zero.
5) Temporal dependence shows a large peak (up to 25 photons per second observed) when the current is turned on suddenly, after a current downtime. This yield depends on the downtime, and is increased for downtimes of an hour or more.

The above results can be understood in terms of standard (but unexpected) chemical models for the cell electrolysis, and diffusion of the deuterium atoms within the palladium. Further measurements are continuing.

Palladium electrodes in H_2O also yield the residual light flux, observed after the current to the cell is reduced to zero.

*Work supported by the U. S. Dept. of Energy, Office of Basic Energy Sciences, under contract W-31-109-ENG-38.
†Graduate Student, University of Illinois, Chicago.

Problems With the Mass Spectral Determination of Tritium from Cold Fusion*

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Albuquerque, NM 87185

Abstract

Among the attempts to measure particles produced in the cold fusion of deuterium in palladium metal is the mass spectrometric observation of tritium. An experiment which has been reported in the popular press involves attaching a hollow Pd electrode to a vacuum chamber and measuring tritium produced during electrolysis using a mass spectrometer. We present data demonstrating that mass 5 and 6, which could be mistaken for the ions DT^+ or T_2^+, can arise from ion/molecule reactions in the ionizer of the mass spectrometer giving the ions D_2H^+ and D_3^+. With H_2 and D_2 present in the vacuum chamber, there are at least 9 reactions which lead to these triatomic species, and these may contribute to a complex time and pressure dependence of the signals. If during electrolysis, tritium were produced at the levels suggested by the Pons & Fleischmann experiment, the DT^+ signal would be insignificant compared to the background generated by ion-molecule reactions.

*This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

COLD FUSION REACTION PRODUCTS AND THEIR MEASUREMENT

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ABSTRACT

The major reaction products that have been associated with cold fusion reactions are: neutrons, protons, tritium, He-4, He-3, internal conversion electrons, and gamma radiation. The branching ratios and relative reaction rates for these products are examined for consistency with cold fusion experiments. Both theoretical calculations and experimental data are examined and will be presented. For example, the He-4 plus internal conversion has been proposed in order to explain the absence of neutrons or gamma radiation. This reaction is not favored, even in a deuterium-palladium system. In the event this reaction occurs, deexcitation of the excited He-4 nucleus would predominantly occur by gamma emission. Even if internal conversion dominates, considerable Bremmsstrahlung radiation would be generated. Either the Bremmsstrahlung or the gamma radiation would also create neutrons from the photodisintegration of deuterium. Measurement of these reaction products must be made carefully owing to their presence in background. For example, the 2.2 MeV gamma ray from Bi-214, background tritium in the heavy water, and neutrons from the photodisintegration of the deuterium from background radiation. These problems will be discussed and experimentally obtained examples will be presented.

Detection of "Cold Fusion" Helium Products by Mass Spectrometry*

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Rocketdyne Division
Canoga Park, CA 91303

and

K. L. Wilson
Sandia National Laboratories
Livermore, CA 94550

Abstract

The detection of helium products would be a most compelling piece of evidence that "cold fusion" is occurring in palladium electrochemical cells. In this paper we report on mass spectrometric measurements of helium (^{3}He and ^{4}He) released from palladium samples through vaporization. Extensive measurements conducted by Sandia National Laboratories on helium-implanted metals and metal hydrides have conclusively demonstrated that helium is not released at ambient temperatures until a He/metal concentration ratio of ≅ 0.4 is achieved. If we assume that "cold fusion" events are creating helium in the palladium electrode with Q = 23.84 MeV, then one watt of fusion power would correspond to a helium production rate of 2.5×10^{11} ^{4}He/s.

While this potential production rate is orders of magnitude below that required for spontaneous release, it can be detected by mass spectrometry of vaporized samples. In the Rockwell International measurements, 10-50 milligram size samples were vaporized under vacuum and all gases were passed through multiple getter stages to remove unwanted gases, including hydrogen isotopes. The helium concentrations were then measured using a precision mass spectrometer. Absolute calibration of the system was verified using palladium samples implanted with 700 keV ^{4}He ions. The ultimate detection level of the system is ≈ 1×10^{10} helium atoms (either ^{3}He or ^{4}He or both) per gram of palladium. Results of helium measurements conducted for a number of U.S. laboratories are presented. In no case was there any "cold fusion" helium detected above system background for palladium electrodes used typically for 1-2 weeks, implying a maximum time-averaged "cold fusion" rate of less than 0.1 microwatts per gram of palladium.

* This work supported by the U.S. Dept. of Energy under contract DE-AC04-76DP00789.

Ion Beam Analysis of Pd Electrodes after Electro-chemical Reactions in D_2O

M. Yanokura, K. Yoshida, and I. Tanihata
LINAC Laboratory, RIKEN
and
M. Aratani and M. Minami
Radiochemistry Laboratory, RIKEN
and
S. Nakabayashi, A. Kira
Chemical Dynamics Laboratory, RIKEN
2-1 Hirosawa, Wako, Saitama 351-01, JAPAN

Ion beam analysis of the Pd electrodes was made after electrolysis of D_2O with several electrolytes of different metal ion mixture. An Ar ion beam from heavy-ion LINAC at RIKEN was used at 61 MeV. Recoil proton, deuteron, and other light elements were detected by silicon solid state detector placed at 33 degree scattering angle. Particle identification was made by the measurements of total energy and the time-of-flight of a particle. Only a very small amount of deuteron was observed in most electrolytes. Instead considerable amount of proton was observed in all cases. It is considered, therefore, that the replacement speed of proton to deuteron in Pd metal is very slow. The slow replacement speed is also observed in other material such as Si.

If the cold fusion is occurring in Pd metal, a sufficient number of deuteron has to be included in Pd. The present experiment give warning for fusion experiments in such a way that the detection of neutron and other radiations has to be made sufficiently after the replacement of hydrogens to deuterium in Pd occurred.

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id AA04372; Sat, 29 Apr 89 16:21:17 PDT
Date: Sat, 29 Apr 89 16:21:17 PDT
From: michael@mike (Michael Nauenberg)
Message-Id: <8904292321.AA04372@mike.chromo.UCSC>
To: rlg2@yktvmv.bitnet
Subject: visit to Utah

Hi Richard,
Enclosed is a report of
my visit last week to
the alchemist lab in Utah
Regards,
Michael
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.nr HM 0.75i
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Physics Department
University of California
Santa Cruz
CA 95064
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May 30, 1989
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Professor Norman Ramsey
Physics Department
Harvard University
Cambridge, Mass. 02138
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Dear Professor Ramsey,

p 2 of 7
7.9,

.PP
As we agreed at the Santa Fe meeting on Cold Fusion,
here is a brief informal report of my visit
last week to the University
of Utah where I was invited by the Physics department to
review this topic (enclosure).
I made some notes
of the conversations and I later checked some facts,
but most of this letter is based on memory.
.PP
On Wednesday , I was invited to have lunch with three chemists
from the University of Utah,
Cheves Walling, Jack Simons and Tony Haymet,
together with a physicist,
Carleton Detar who was my host.(Carleton was and undergraduate
at Harvard and told me he has taken some of your courses
there).
Walling and Simons have written a "theoretical" paper
in which they state that deuteron fusion in Palladium occurs
predominantly by forming Helium 4, with the energy transfer
given off primarily by
internal conversion to the lattice. Some weeks ago they had told
me that Pons and Hawkins had carried out mass spectrometry
measurements and found about 10**12 He4 / cc. sec. formed in
Palladium; exactly
what is needed to account for the claimed energy.
(In confirmation Haymet had sent us a bitnet message in which
he expressed surprise that we doubted this measurement).
Their paper is a
speculation based on the notion of the existence in
the lattice of electrons with
effective mass 10 times the mass of the electron.(Steve
Koonin and I introduced this effective mass previously
as a convenient way to scale
distances and energy in order to obtain
the rates of fusion claimed by Pons and Fleischman. However,
we indicated that this effective mass is devoid
of any physical meaning) (enclosed).
At the lunch I inquired about the status of the Helium 4
measurements, and I was told that subsequent mass spectrometer
measurements
had not confirmed the earlier reports. Walling told me that
he believed that the molecular deuteron peak had a tail that did not
allow the resolution of the much smaller Helium 4 peak .
(Previously I was told the opposite, i.e. that they had
good resolution. Today I learned from Michael Salomon, a
cosmic ray physicist working with Pons, that the mass
spectrometer at Utah was heavely contaminated with helium, and
that
after properly cleaning it, no more helium was observed).
However, it appears that these two chemist continue to believe
in their theory and in the fusion origin of the claimed excess
heat in the Utah experiments. As a sideline, they
mentioned that Julian Schwinger had expressed interest in
the experiment and their theory, and that he had visited the
lab of Pons. You might want to get in touch with Schwinger
to get his opinion.
.PP
After lunch Simmons gave me a tour of Pons' laboratory
which is suppose to be under guard at all times. However,
I did not see any guards when we went in or out of the lab.

Inside the lab I met
the graduate student who has been working with Pons and
Fleischman , Marvin Hawkins, (whose name was belatedly
included as a coauthor in their paper), and a postdoct, Mark
Anderson, who is now also working on the experiment. In the
middle of the lab I was shown four
cells lying inside a water
bath, and in a corner two more cells actively bubbling.
Underneath the water bath there was lead shielding around
a gamma ray counter, which I later learned consisted
of a 4" by 8" sodium iodide
crystal set up by Michael Salamon. He has also made a neutron
counter consisting of uranium 235 embedded in a plastic
polymer which is subsequently etched to search for fission
tracks induced by thermal neutron. Salamon told me that
his preliminary results are
negative. Salamon is also trying to
up a neutron counter to measure energetic neutrons which
requires some modification of Pons' cells (need to make a
millar window which Pons' seems
unwilling to do)
The cells in the lab are the same as shown in the Newsweek article
on cold fusion in the color photo with the
setting sun (enclosed).
In particular one can see in
the photo the resistors used to calibrate the cells. The
thermometer is at a fixed distance (about half way down the
cell) and approximately equidistance from the resistors and
the palladium cathode. We were told that the heavy water
is always kept above the top of the Palladium cathode
by replacing twice a day
the water lost by electrolysis (about one mml.)
Simons told me that he would try to arrange the next day a meeting
with Pons, but this did not work out. (Pons told him he had to
to go to various meetings and take Fleischman to the airport).
From my point of view, this turned out to be fortunate, because it
gave an excuse for Carleton and I to have a discussion with Hawkins
and Anderson. (Carleton, although he is a faculty in the Physics
Department at Utah, had never been able to visit Pons's lab. or meet
either Hawkins or Anderson).
From the experience of others
I doubt that we would have learned anything useful by talking
with Pons or Fleischman.
.PP
Hawkins and Anderson told us that they calibrate the cell
with a known current trough the resistors and then measure
the equilibrium temperature of the cell. Their
assumption appears to be that measuring the temperature "at a fixed
position in the cell" during electrolysis determines the heat
output from the calibration curve. We asked them about the
problem of temperature gradients which has been
pointed out by many people in
the past. In particular it is evident that during electrolysis
the cell is bubbling with the gasses formed, and therefore it
is in a
different state than when it is heated by the
resistors. They answered that they think that the rapid dispersion
of a dye (shown on television by Pons at the Electrochemical
Society meeting at Los Angeles) demonstrates that the
temperature is uniform trough the cell (which we think is
wrong). However, they are now finally checking

this assumption by varying the location of the thermometer in
the cell, but they did not tell us what they have found.
They do not appear to be concerned that
heat loses trough the neck of the cell may be important
and quite different when heating by a resistor and
by electrolysis. In a recent occasion one of the cells
reached boiling temperature
(according to Michael Salamon, who
witnessed the even) with rapid
loses of water vapor. It is unclear whether in this case the top
of the palladium cathode emerged outside of the fluid
.PP
I was also invited to visit the lab of Professor Milton
Wadsworth, who is the dean of Metallurgy at the University
of Utah. Wadsworth is conducting electrolysis experiments
with Palladium cathodes (apparently from the same source
as P/F). When Carleton and I walked into his lab there was
glass on the floor from a recent explosion in one of the cells.
Professor Wadsworth showed us his cell and a temperature
recording which showed a step function increase in temperature
of some ten degrees followed by a slow decay for about 40
minutes after which the temperature dropped rapidly to a
slightly higher equilibrium value than the initial one.
We observed that the heavy water is
below the tip of Wadsworth's Palladium cathodes, which are
covered with a loosely fitted glass top. Thus it is likely
that Wadsworth is observing the Dobereiner "cigarette lighter
effect", recently demonstrated again by some German
chemists. An interesting comment was made by Fleischamn
when Wadsworth showed his results at a recent meeting
at the University. Fleischman
is reported to have said something like
"where have we seen such rapid temperature changes before ?".
However, in the current experiments, as reported by
Hawkins, the temperature raise in Pons's cells is slow.
.PP
I learned today from the press that the request of your committee
to visit Pons and his lab has been declined.
(I suppose he worried that Steve Koonin would show up in his
colorful T-shirt).
I am not surprised at all.
As you may know, I predicted that Pons and
Fleischman would not show up in Santa Fe.
For your information, I have included a letter which
has been sent to the faculty and staff of the
University of Utah by its President , Chase N. Peterson,
last week. It seems to me that this letter
accounts for some of the confusion which has been created surrounding
this subject for the past two months. Rather than seeking
the truth, Peterson and his administrators and lawyers,
with Pons' active participation,
are trying to suppress relevant information.
Sceptics are chastised because they undermine Peterson and
Pons' attempts of
obtaining federal and state funds for cold fusion research
at the University of Utah. In the interest
of some of the
scientist from Utah mentioned in this letter who may suffer
repercussions, I would like to
suggest that this letter be kept reasonably confidential,
i.e. not included in worldwide network news on cold

fusion.
.sp 2
.ti 15
Regards,
.sp 2
.ti 15
Michael Nauenberg
.sp2
.ti0
cc. Steve Koonin, Doug Eardley, Bob Schrieffer, Richard Garwin

0551613 608
USA-FUSION:U.S. LAB SAYS COLD FUSION POSSIBLE BUT CHEAP ENERGY UNLIKELY
DATELINE: SANTA FE, N.M. PRIORITY: Urgent
Reuter Library Service DATE: MAY 25, 1989 07:10 G.M.T.
WORD COUNT: 211

The Los Alamos National Laboratory on Wednesday backed controversial claims that nuclear fusion can occur at room temperature but said the process would probably never supply cheap energy.

Los Alamos physicist Howard Menlove told reporters he had "no doubt" a nuclear reaction of some sort occurred during U.S.-funded experiments duplicating the cold-fusion work of two scientists in Utah.

But Menlove said the reaction did not produce enough energy to be considered a likely source of cheap or viable power.

Menlove said neutrons were released, proving that a nuclear reaction was occurring. But he said the mechanism that produced the neutrons has not been identified.

Two chemists working in Utah stunned the scientific world on March 23 by announcing they had achieved fusion at room temperature in an ordinary bottle on a laboratory table top.

The report of Stanley Pons of the University of Utah and Martin Fleischmann of Britain's Southampton University raised hopes that a safe and cheap source of energy had been found. But their conclusions have been widely disputed.

They declined to attend the Santa Fe conference.

The Los Alamos National Laboratory, operated by the University of California for the U.S. Energy Department, is located on the site in northeastern New Mexico where scientists developed the first atomic bomb.

DESCRIPTORS: SCIENCE

05/24/89

①

RLG talk Wednesday night.

Regret F&P declined to participate. My comments the same as 04/12/89 at the conference in Sicily

1) Steve Jones BYU --
neutrons 170 ± 27 -- ; more later. } ~ 1 n/s, 1 f/s. }

2) F&P. -- Heat; -- T; -- He^4, -- n (gammas). ~ 10^3 n/s
1W = 2×10^{11} He^4/s

Note Lewis & others here -- lack of stirring exp on calibration; evap, recomb.

Unless directly-measured heat out exceeds V·I, I believe it undemonstrated that any "excess heat" has been generated --

-- slide -- even so. V·I - - - - [Huggins] closed cell! [O_2 excess!?]

100 cpm (T)/ml in a 10 ml cell 30% eff. $\lambda = \frac{1}{20 y} = 1.6 \times 10^{-9} s^{-1}$ ≈ 10^{-7} m

so 100 cpm → 300 × 10^7 × 10 = 3×10^{10} atoms.

at $10^3 s^{-1}$ this would be 1 yr !!

If p + t & n + He^3 about equally probable,
100 cpm/ml would be 10^3 n/s for one year.
for one day would be ~~300,000~~ 3×10^5 n/s.
10^6 cpm/ml " " would be 10^7 n/s for one year; 3×10^9 n/s for one day.

1 W of electrolysis; 1 W of fusion. $\frac{3.06}{23.8 MeV}$ = 0.12 × 10 ppm
if all He enough!!

"1-10 ppm."

05/24/89
②

neutron bursts

Counters count thermal neutrons produced by [illegible] of fast n.

~ surely not neutrons? unless [illegible] -- .

 -- no sign of bursts

Barrier penetration f. $B = e^{-2\int_0^{r_c} k(r)\,dr} = e^{-41.13\sqrt{\mu}}$

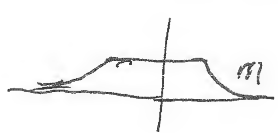
μ = reduced mass...

$p = \hbar k$ $\frac{p^2}{2m} = E - V = E - \frac{Ze^2}{r}$

$k = \frac{1}{\hbar}\sqrt{2mE - 2m\frac{Ze^2}{r}}$

Oppenheimer-Phillips effect $D \to n$. despite charge in [illegible] [illegible] cross- [illegible]

why — at nuclear surface. r_s $k_D \sim \sqrt{\frac{2 M_D Ze^2}{r_s}}$ high Z, $\frac{Ze^2}{r_s} \sim$ 10 MeV



$\sim \sqrt{\frac{2 \times 2 \times 10 \text{ MeV-amu}}{40 \text{ amu-MeV}}}$ } $\to \sqrt{\frac{2 \times 1 \times 0}{1.2}}$

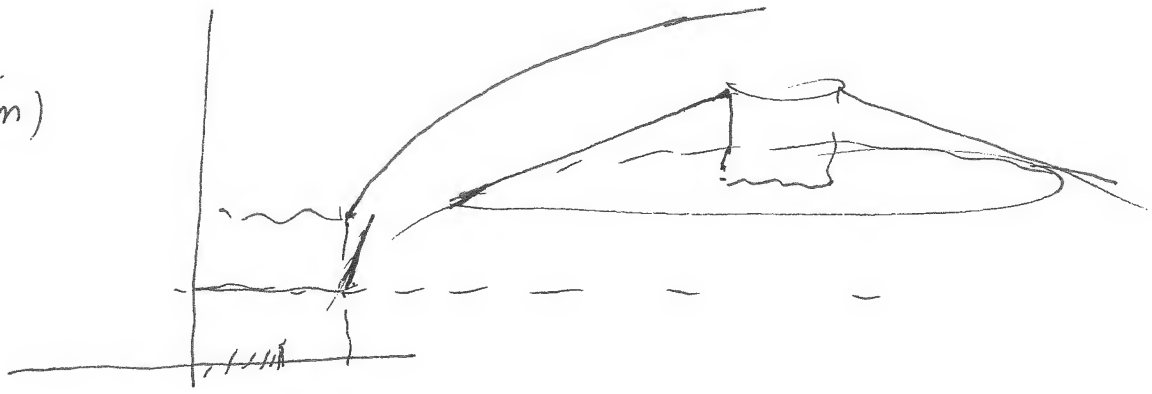
but k_n starts out of D is $\psi \sim e^{-k(r - r_D)} = e^{+kr_D} e^{-k_n r}$

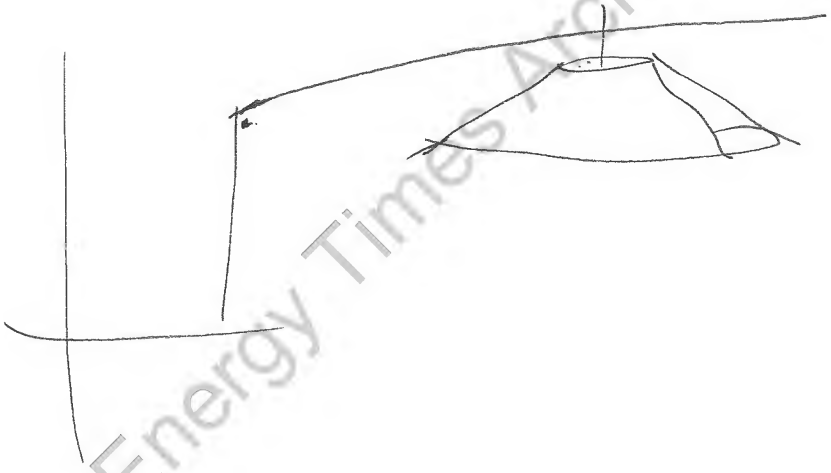
$\hbar^2 k_n^2 = 2\mu E_B = 2 \times \frac{1}{2}\, 2.223 \text{ MeV}$

$k_n = \frac{1}{\hbar}\sqrt{2.223 \text{ amu-MeV}}$ }

05/24/89
(3)

$\log \Psi^2(n)$





— T from volcanoes — F. Bressi

— Drexel University Michael Baranum

— D-D polarization

— pyroelectric effect x

MIT

→ 80°C Content $\frac{116 \text{ neutrons}}{5 \times 10^{-5}} = 3 \times 10^6 n$

F.ig ~ 0.07 M

~ 4×10^{22} Pd = 10^{21} eV ~ 0.02 eV/atom

→ 10^{14} He^4

Bogey collaboration -- Frejus tunnel

x 3,000 per FLP ; ~ 300 per Frascati

~ 200 per Jones.

1→2

----- FUSION FORUM appended at 10:52:25 on 89/05/22 GMT (by BCOURTNE at DETVMIC1)
Subject: Workshop on cold fusion phenomena

(agenda is after the satellite information)

WORKSHOP ON COLD FUSION PHENOMENA [Uplink Information]
MAY 23-25, 1989
SANTA FE, NEW MEXICO

Sponsored by Los Alamos National Laboratory
and the U.S. Department of Energy

May 23rd, 9:00am - 5:00pm and 7:30pm - 9:30pm MDT
May 24th, 8:00am - 5:00pm and 7:30pm - 9:30pm MDT
May 25th, 8:00am - 12:00pm MDT

By SATELLITE:

Ku-Band: SpaceNet 1, SP1 120 W, TR# 24, Audio 6.2 & 6.8MHz

C-Band: WESTAR 5, W5 122.5 W, CH# 4 (2X), Audio 6.2 & 6.8MHz
C-Band (evening sessions): TELSTAR 301, 96 W, CH#21 (11V), Audio 6.2 & 6.8MHz

AGENDA

WORKSHOP ON COLD FUSION PHENOMENA
May 22--25, 1989

SWEENEY CENTER, SANTA FE, NM
Monday, May 22

Workshop participants arrive in Santa Fe

4:00 -- 8:00 Registration and badge issue at
Eldorado Hotel---Hospitality room
available at Eldorado Hotel

Tuesday, May 23

7:30 -- 8:00 Arrival at Sweeney Center

8:00 -- 8:30 Late Registration
8:30 -- 9:00 Preliminary Remarks — Reed J. Jensen
-- Welcome — Sig Hecker
-- Introduction of Workshop — Norman Hackerman

9:00 -- 12:00 First Plenary Session (A)--- Integrated Experiments — Moderator: Reed J. Jensen, Los Alamos National Laboratory

9:00 -- 9:30 Evidence for Excess Heat Generation Rates During Electrolysis of D2O in LiOD Using a Palladium Cathode - A Microcalorimetric Study (Invited Talk) — A.J.Appleby, S.Srinivasan, O.J. Murphy, C.R. Martin, Texas A&M

9:30 -- 9:50 Neutron Emission and the Tritium Content Associated with Deuterium Loaded Palladium and Titanium Metals — K.L. Wolf, N. Packham, J. Shoemaker, F. Cheng, D. Lawson, Texas A&M

9:50 -- 10:20 BREAK -- Refreshments Available

10:20 --	Electrochemical ■Cold Nuclear Fusion'' Attempts at IPP	G.A. Wurden, LANL H.S. Bosch,J. Gernhardt, G. Janeschitz F. Karger,J. Perchermeier Max Planck Institut fur Plasma Physic FR Germany
10:40 --	Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes	D. Albagli,V. Cammarata, R. Crooks,M. Schloh, M.S. Wrighton,X. Chen, C. Fiore,M. Gaudreau, D. Gwinn,P. Linsay, S.C. Luckhardt,R. Parker, R. Petrasso,K. Wenzel, R. Ballinger,I. Hwang,MIT
11:00 --	In Search of Nuclear Fusion in Electrolytic Cells and Metal/Gas Systems	D.R. McCracken, J.Paquette, R.E. Johnson,N.A. Briden W.G. Cross, A. Arjena, A.M. Lone,D.C. Tennant, W.J.L. Buyers Chalk River Labs, Ontario
11:20 --	LUNCH/POSTER SESSION	
1:30 --	5:00 Second Plenary Session (B)--- Integrated Experiments (Cont'd)	Moderator: Fred Morse Los Alamos National Laboratory
1:30 --	Search for Neutrons from Cold Fusion in Ph-D	R.S. Raghavan,L.C. Feldman M.M. Broer,J.S.Kraus, A.C. James,D.W. Murphy AT&T Bell Labs
1:50 --	Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in D2O	Nathan S. Lewis Charles A. Barnes Cal Tech
2:10 --	Search for Fusion in Deuterated Transition Metals: Dynamical Pressures Above 1 Megabar	F.M. Mueller,K.A. Johnson, W.J. Medina,A.R. Mantheia, C.L. Talcott,E.K. Storms J.W. Shaner,B.L. Freeman J.E. Vorthman,M.M. Fowler LANL
2:30 --	Tests for ■Cold Fusion'' in the Pd-D2 and Ti-D2 Systems at 350 MPa and 195-300K	J.G. Blencoe,M.T. Naney D.J. Wesolowski ORNL
2:50 --	Measurements of Heat, Neutron and ? Flux Induced by ? Stopped in Deuterium Saturated Targets	M.Chen,S. Steadman, MIT C.Fiore, M. Gaudreau S. Luckhardt,R. Parker, MIT R. Crooks,M. Schloh, D. Albagli,V. Cammarata, M. Wrighton, MIT R. Debbe,D. Lowenstein, BNL

3:10 --	High Precision Cold Fusion Calorimetry Achieved by In Situ Catalytic Recombination of Evolved Gases	M.E. Hayden,U. Narger, J.L. Booth,L.A. Whitehead, W.N. Hardy,J.F. Carolan, D.A. Balzarini,C.C. Blake E. Wishnow,Univ. of British Colum Vancouver, Canada
3:30 --	BREAK -- Refreshments Available Physics of Fusion Reaction	
4:00 --	Nuclear Reactions and Screened-Coulomb Fusion Rates	G.M. Hale,R.D. Smith, T.L. Talley, LANL
4:20 --	Molecular Dynamics Simulation of PD1:1: How Close Can Deuterons Ge	Peter M. Richards SNL
4:40	Conditions Leading to the Production of Cold Fusion Neutrons	M. Gajda,G. Harley J. Rafelski Univ. of Arizona
	Electrochemical Experiments in Cold Nuclear Fusion	J.F. Ziegler,T.H. Zabel, J.J. Cuomo,V.A. Brusic G.S. Gargill III, E.J. O'Sullivan, A.D. Marwick,R. Garwin IBM Rsch.Div., Thomas J. Watson Research Center

5:00 -- 5:30 BREAK -- Walk to Eldorado Hotel

5:30 -- 7:00 Reception at Eldorado Hotel
7:00 -- 7:30 Return to Sweeney Center

7:30 -- 9:30 Discussion Period with Presenters J. O'M. Bockris

Wednesday, May 24

7:30 -- 8:00 Arrive at Sweeney Center
8:00 -- 12:00 Third Plenary Session (C)--- Moderator: C. A. Barnes
Neutron & Gamma-Ray Spectroscopy Cal Tech

8:00 --	Cold Nuclear Fusion in Condensed Matter: Recent Results and Open Questions (Invited Talk)	S.E. Jones BYU

8:30 -- Experimental Evidence for Cold Nuclear Fusion in a Measurement Under the Gran Sasso Massif	A. Bertin,M. Bruschi, M. Capponi,S. DeCastro, U. Marconi,C. Moroni, M. Piccinini, N. Semprni-Cesari A. Trombini,A. Vitale, A. Zoccoli, Instituto Nazionale Di Fisica Nucleare, Italy J.B. Czirr,G.L. Jensen S.E. Jones,E.P. Palmer BYU
8:50 -- Neutron Emission from a Titanium-Deuterium System (Invited Talk)	A.De Ninno,A. Frattolillo, G. Lollobattista,L. Martinis, M. Martone,L. Mori S. Podda,F. Scaramuzzi Centro Ricerche Energia Frascati, Italy
9:10 -- The Measurement of Neutron Emission from Ti Plus D2 Gas	H.O. Menlove,M.M. Fowler E. Garcia,A. Mayer, M.C. Miller,R.R. Ryan LANL S.E. Jones, BYU
9:40 -- Upper Limits on Emission Rates of Neutrons and Gamma-Rays from [redacted]Cold Fusion'' in Deuterided Metals (Invited Talk)	M. Gai,S.L. Rugari, R.H. France,B.J. Lund, Z. Zhao, Yale A.J. Davenport,H.S. Isaacs, K.G. Lynn, BNL
10:10 -- BREAK -- Refreshments Available	
10:40 -- Lack of Neutron and Gamma Radiation from PPPL's Cold Fusion Experiments	H.Hsuan,D. Manos, S. Cowley,R. Motley, L. Roquemore,T. Saito, J. Timberlake,W. Ayeres, T. Bennett,M. Bitter E. Cecil,S.C.J. Cuthbertson, H.F. Dylla,H. Furth, L. Grisham,H. Hendel, K. Hill,R. Kulsrud,D. Meade, S. Medley,D. Mueller, E. Nieschmidt,R. Shoemaker, J. Thomas Princeton University
11:00 -- An Attempt to Measure Characteristi X-Rays from Cold Fusion	R. Fleming,F. Donahue, S. Mancini,G. Knoll, B. Heuser, Univ. of Michigan
11:20 -- LUNCH/POSTER SESSION	

1:30 -- 5:00 Fourth Plenary Session (D)--- Moderator: Anthony Turkevich
Calorimetry University of Chicago

1:30 --	Two Fast Mixed Conductor Systems-- Deuterium and Hydrogen in Palladium	A. Belzer,U. Bischler, S. Crouch-Baker,T.M. Gur, M. Schreiber,R.A. Huggins
2:00 --	Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells	N.A. Godshall,E.P. Roth, M.J. Kelly,T.R. Guilinger, R.I. Ewing, SNL
2:20 --	The Possibility of Evaporation Dominating [redacted]Cold Fusion'' Power Balance Calculations	A.E. Pontau SNLL
2:40 --	Calorimetric Measurements on Electrochemical Cells with Pd-D and Pd-H Cathodes	L. Redey,K.M. Myles, D. Dees,M. Krumpelt, D.R. Vissers, ANL
3:00 --	Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis	D.E. Stilwell,M.H. Miles Naval Wpns. Cntr.
3:20 --	BREAK -- Refreshments Available	
	Physics of Fusion Reactions--II	
4:00 --	Seven Chemical Explanations of the Fleischmann-Pons Effect	J.O'M. Bockris,N. Packham, O. Velev,G. Lin, M. Szklarzcyck, R. Kainthla, Texas A&M
4:20	Evidence Against Condensed Matter Fusion Induced by Cosmic-Ray Muons	K.Nagamine,T. Matsuzaki, K. Ishida,S. Sakamoto, Y. Watanabe,M. Iwasaki, H. Miyake,K. Nishiyama, H. Kurihara,E. Torikai, T. Suzuki,S. Isagawa, K. Kondo University of Tokyo/RIKEN
4:40 --	DINNER/POSTER SESSION	
5:30 --	7:00 Optional, No-Host Buffet at Eldorado Hotel	
7:30 --	9:30 Discussion Period with Presenters at Sweeney Center	M. Broer

Thursday, May 25, 1989

7:30 -- 8:00	Arrive at Sweeney	
8:00 -- 12:00	Fifth Plenary Session (E)---Applicable Condensed-Matter Physics, Applicable Electrochemistry, Analytical Chemistry of Appropriate Products	Moderator: Johann Rafelski University of Arizona
8:00 --	PAC Studies of Electrolytically Charged Metal Cathodes	G.S. Collins,S.L. Shropshire, Jiawen Fan Washington State Univ.
8:20 --	Interaction of Deuterium with Lattice Defects in Palladium	F. Besenbacher,B.B. Nielsen, S.M. Myers,P. Nordlander, J.K. Norskov University of Aarhus Denmark
8:40 --	Search for Cold Fusion in Superstoichiometric Palladium Deuteride Using Ion Implantation	S.M. Myers,D.M. Follstaedt, J.E. Schirber,P.M. Richards SNL
9:00 --	Tritium Enrichment in the Electrolysis of D2O	J. Bigeleisen State Univ. of NY Stony Brook, NY
9:20 --	Nuclear Fusion from Crack-Generated Particle Acceleration	F.J. Mayer,J.S. King, J.R. Reitz FJM Assoc., Univ. of Michigan Ford Motor Rsch. Lab
9:40 --	Search for 0.8 MeV 3He Nuclei Emitted from Pd and Ti Exposed to High Pressure D2	S.W. Barwick,P.B. Price, W.T. Williams UC--Berkeley
10:00 --	BREAK -- Refreshments Available	
10:30 --	Workshop Summary/Wrap-Up	R. Schrieffer, N. Hackerman
12:00 --	Workshop Concludes	

Bill Courtney

SECTION: Financial News
STORY TAG: Sweden-ColdFusion
DATELINE: STOCKHOLM, Swede (AP) May 23, 1989
TIME: 0958PDT CYCLE: PM
PRIORITY: Regular WORD COUNT: 0350

Swedish physicists said today they produced a burst of neutron radiation in a room-temperature experiment, repeating the work of two chemists who claimed to have achieved cold fusion in a jar.

The scientists at the Manne Siegbahn Institute for Physics said their method was similar to the experiment that chemists Stanley Pons and Martin Fleischmann said they conducted at the University of Utah.

In March, the two claimed to have produced sustained fusion in a jar at much colder temperatures than previously thought possible. Repeated attempts by other scientists to duplicate the Fleischmann-Pons experiments have failed.

Birger Emmoth, Magnus Jandel, Irena Gudowska and Waclaw Gudowski said in a press release they ran an electrical current between platinum and palladium electrodes immersed in heavy water containing deuterium, a variety of hydrogen.

"The results indicate fusion reactions can occur at low temperatures in the electrode material palladium. This gives certain support to Fleischmann and Pons ideas," the release said.

The results were reported in a paper to be published by the scientific journal Physica Scripta. It did not say when their findings might appear in the journal.

In their tests, the scientists obtained increasing neutron radiation reaching a level up to 10 times greater than natural background radiation and lasting up to four hours.

The group said the experiment is difficult to repeat because many factors can affect the process. In some case their tests produced no surplus neutrons.

Birger Emmoth told Stockholm daily, Svenska Dagbladet, the tests were easier to repeat using new palladium plates of sufficient size, rather than already used plates and small ones.

Electrodes used by the group were three millimetres thick and weighed 40 grams, Svenska Dagbladet said.

"Also the character of a time limited 'burst' of course are in line with (Pons and Fleischmanns) results, even though theirs were longer, almost 24 hours," he said.

Their experiments, in cooperation with the Royal Institute of Technology and Arrhenius Laboratory in Stockholm, began in early April.

11G

-R.L. GARWIN

20 JUN 89 13. 8

A Report on the Workshop on Cold Fusion Phenomena
May 23 - 25, 1989, Santa Fe

by Robert E. Chrien
Physics Department
Brookhaven National Laboratory

Distribution:
J. Bigeleisen
R.E. Chrien
R.L. Garwin
J.R. Huizenga
N.F. Ramsey
J.P. Schiffer

052389.REC

Cold Fusion

A Report on the Workshop on Cold Fusion Phenomena

May 23-25, 1989, Santa Fe

by Robert E. Chrien

On May 23, 1989, approximately 450 participants assembled at the Sweeney Conference Center, Santa Fe, to attend a "workshop" on cold fusion phenomena. They were supplemented by about 50 reporters and science writers; the proceedings were broadcast by satellite to university and commercial viewers. There were 110 papers presented, the majority of which were shown as posters. About thirty-five papers were presented orally. The sessions ran from 8:00 a.m. to 5:00 p.m., and several hours of discussion were scheduled on Tuesday and Wednesday evenings.

This report on the phenomena called "cold fusion" reflects my interpretations on what was heard there. I have tried to make notes accurately, but I cannot guarantee that accuracy since I have not checked against publications or preprints (except in a few cases).

The phenomenon of "cold fusion" was suggested by Pons and Fleischmann (who did not show up at this conference) at their news conference in March 1989 and in subsequent reports and conferences. Pons and Fleischmann claimed to measure "excess heat" in an electrolytic cell containing a Pd cathode and electrolytes such as NaOD dissolved in D_2O. By "excess heat" one means the energy in excess of that required to dissociate D_2O, which is supposedly not recombined. Pons and Fleischmann could not conceive of any chemical reaction which could be responsible for this excess heat, and therefore suggested that fusion reactions were responsible. They pointed out that through electrolysis the Pd (or Ti or other metals) could be loaded with deuterium; more deuterium than in fact is present in a 1:1 ratio of Pd/D. Such excess stochiometric ratios are achievable--in fact up to 1:1.3 is made by implantation. They suggested that the deuterium are squeezed together to produce fusion reactions. Steven Jones and colleagues at BYU have suggested such phenomena in the past. Jones et al. do not claim to have observed heat production. They claim to observe neutrons from (D,D) reactions.

These and similar claims have produced a flurry of excitement and activity such as has not been seen in nuclear physics since the discovery of fission. This workshop was meant to bring together the claims and counterclaims, the theorists and experimenters, the chemists and physicists, the proponents and skeptics, and all the bemused general public.

In this report I present the interpretations gleaned from this meeting in a highly subjective way. The order of presentation is not descriptive of the meeting; it is more indicative of the logical structure with which I approach the subject. I will not address the reports of excess heat production as I am not qualified to comment here. There were many more negative reports than positive ones.

Since the suggestion is that fusion reactions are taking place, the first step is to consider the nuclear physics. The subject was carefully addressed by Gerry Hale of LANL, who as an expert in R-matrix theory, has been analyzing low-energy light ion reactions for 20 years. These play an important role, not only in "hot fusion", but also in stellar energy production. However, the concepts necessary to understand such reactions go back to the compound nucleus theory of Niels Bohr.

Figure 1 illustrates the compound nucleus ^{4}He formed upon fusion in a pair of deuteriums. An excited system of ^{4}He is formed at Ex $\approx$ 23.8 MeV; as Bohr taught us that system then decays without a memory of how it was formed. Elementary considerations about the strength of the nuclear and electromagnetic forces suggest that the decay is primarily by particle emission. In fact the radiative branching ratio is 10^{-8} of the total decay. The decay is roughly 50-50 between (t+p) and (^{3}He+n). A reference to fig. 1 shows that on a nuclear scale, where Ex $\approx$ 23.8 MeV, there is little difference between hot fusion, where the relative DD energies are a few keV, and "cold" fusion where the relative DD energies are a few eV. Hale's talk was largely addressed to these differences; the crux of the matter is shown in fig. 2, where the DD cross section is shown extrapolated from the tens of keV region, where it has been measured, down towards zero. There is at most a 4% change

in the branching ratio. All the talk of a neutron-less, or a pure γ-ray form of fusion violates what we know about fundamental nuclear theory and should be dismissed by right-thinking people.

The small differences in branching ratio which are observed are due to the effects of P-wave (and for radiative capture) D-wave which mix with the dominant S partial wave component near zero relative kinetic energy for the deuterons. Such effects are not large and may be ignored in this discussion of fusion. See figs. 2-4.

These remarks pertain only to unpolarized particle reactions. There is no reason to consider the interactions of polarized deuterons, as there is no polarization in the targets considered. While one paper (Collins et al.) refers to a spin-dependent tunneling process, there is no evident mechanism for this.

One other theme of Hale's talk is important here. That is the effect of electron screening on the D-D potential. Briefly, Hale showed that to get "appreciable" fusion rates an impossibly high (a_0 = 0.39 Å) electron density is required. Here "appreciable" means a fusion rate at the background level of particle detection for the typical NE213 neutron scintillator ($\approx$0.1 neut/sec). Such a rate is about 10^{-23} fusions/sec/deuteron pair.

In a related talk, Peter Richards of Sandia asked the question: how close can deuterons get in a computer simulation of the PD1.1 lattice? Richards assumed a very conservative screening length ($a = a_0/2$ or 0.52/2 Å) and no spacings were found less than 0.7 Å. Note that in D_2 gas 0.74 Å is obtained. Hence the conclusion that loading Pd with D_2 can produce no effect not seen in ordinary D_2 gas at the same temperatures! This corresponds to a fusion rate less than 10^{-70}!

Rafelski and his collaborators have arrived at similar conclusions. They emphasize that in any equilibrium situation, fusion rates at room temperature are negligible. Only a non-equilibrium situation can produce effects, such as

the formation of a hot plasma due to some catastrophic collapse of a microscopic cavity in a sudden expansion of crystals under stress. No such model was presented by them. However, the only non-equilibrium model which seemed at all possible was presented by Frederick J. Mayer, J. S. King and J. R. Reitz. They noted, first, that reports of neutron and charged particle production from suddenly fractured materials appear in literature from the USSR (V. A. Klyuev et al.). Mayer et al. propose acceleration of deuterons across charged surfaces which separate to form minute gaps. They arrive at voltages of 10 keV or more which persist for picoseconds. This effect could be responsible for the detection of neutron bursts at LANL and Frascati, from titanium and palladium under high D_2O pressure, as the material warms. This theory provides the only possible mechanism for fusion offered at Santa Fe--it is "hot" fusion and not cold fusion. No mechanism for cold fusion was reported.

The experimental situation is at best, chaotic. Positive and negative evidence abounds. It is quite clear that many experiments have been hurriedly assembled and are meaningless. I comment on only about 20% of the reported results; these are representative of the total variety, which number nearly 100. Some experiments report heat generation, some tritium production, and some neutron production. No experiment reports charged particle detection at a significant level.

The Texas A&M results are illustrative of this chaos. They are in fact interpretable as the best evidence against fusion as an explanation of this phenomenon. Texas A&M (Appleby) reports 1) excess heat at the level of 40 milliwatts/gm of Pd (agrees with Utah rates of Pons and Fleischmann), 2) Kevin Wolf reports a neutron rate of 4/sec (10 x Jones rate), and 3) tritium production (3×10^{14} atoms of ^3H after 10 hours of electrolysis). Figure 3 shows these rates placed in terms of fusion/deut/sec. These reported rates of 10^{-10}, 10^{-13}, and 10^{-23} fusions/deuteron pair/sec differ by many orders of magnitude and are strongly inconsistent with a single process as their origin. It seems to me to be fruitless to search for a single cause for such data (fig. 5).

It is worthwhile to comment on the different neutron detection experiments reported. For the positive results, one notes that the reports all tend to detect neutron levels at or near the detector sensitivity. For the most sensitive detector, no neutrons are reported, at a level of 500 below the Jones report (corresponding to 10^{-23} fusions/deut pair/sec). Table I is a listing of neutron detectors. For each I list a figure of merit, $S = \varepsilon/B$, where ε is the efficiency (including solid angle) and B the "background" rate. Thus the figure of merit is simply the inverse of the neutron emission rate corresponding to a unity signal to background ratio.

The best neutron detectors provide 1) a definite neutron "tag" resulting from neutron capture, 2) good discrimination against γ rays, 3) high efficiency, and 4) good timing. Unfortunately, no detector provides all 4. The Texas A&M detector provides none of these 4 desirable quantities. Any detector relying only on the use of pulse shape discrimation to distinguish between neutrons and γ rays is to be viewed with great suspicion. It is well known, that, as $E_n \to 0$, the discrimination against γ's becomes progressively worse. Based on my experience in the use of NE213, I would view any neutron detection claims at 2.0 MeV with great suspicion, as there is bound to be γ sensitivity at such energies.

The first entry of the table refers to Bart Czirr's neutron detector, as used by Steven Jones, fig. 6. It has a positive neutron tag derived from a signal from a lithium glass detector. It has, unfortunately, a surprisingly high background and γ-sensitivity which I attribute to the poor performance of the ^{6}Li glass detector and the poor ^{6}Li glass discrimination against γ rays. The Texas A&M detector has the worst performance of the whole group and should be discounted. The Yale-BNL detector uses neutron time-of-flight to enhance the performance of NE213 with pulse shape discrimination; its performance is comparable to the BYU detector. The Gran Sasso detector, developed by a Bologna group under A. Bertin uses NE213 with pulse-shape discrimination and carries the same objection to all such detectors. In spite of its location in the Gran Sasso tunnel, it shows a background worse than that of the Czirr detector. It has a higher efficiency, however. The ^{3}He-moderated detectors

such as LANL, Chalk River, and Frascati all have excellent discrimination against γ's and can have high efficiency, as is displayed by Menlove's detector, with its many ^{3}He tubes imbedded in polyethylene. The best neutron detector by far is the one developed by the Bugey collaboration and reported by Desclais. This is a very large, modular, ^{6}Li-loaded (0.15%) NE320 scintillator, with 98 separate elements, each 8.5 x 8.5 x 85 cm long. A positive α-triton tag is obtained from the ^{6}Li capture. All pulse profiles are digitized by flash encoders and all cuts are applied off line. Such cuts include pulse amplitude, pulse timing (moderator delay between scintillator and Li signals), and spatial cuts (to relate the distance between slowing down and capture of the neutron). A display of the data revealed beautiful neutron and γ discrimination. The whole device was moved to the Frejus tunnel, whose very low backgrounds were observed--2 counts in 5 days! No events from a Jones-type cell were seen, at a sensitivity corresponding to 500 times better than Jones had.

Several charged particle detector schemes based on silicon surface barrier detectors were employed to observe the tritium-proton decay branch. The most sensitive, by far, was reported by Ziegler et al. from IBM, who fail to see charged particles from a Jones-type cell, using Pd cathodes, and infer a limit of less than 10^{-25} fusions/deut pair/sec--at least 100 times better than Jones' sensitivity. Unfortunately, the IBM paper was not presented orally, and I therefore do not know whether their results are still put forward as valid. The report by Meyers of Sandia was one of several which used a low energy acceleration to implant D_2 into palladium, and the (D,D) reaction was used to monitor the implanted deuterium thickness. No charged particle events were observed where the bombarding current is turned off, but due to the thinness of the implanted deuterium layer the sensitivity is not high.

Steven Jones spent most of his invited talk retracing his involvement in cold fusion speculation. He took the occasion to reduce his claimed cold fusion rate from 10^{-23}, as quoted in the Nature publication, to near 10^{-24}, based on the average of the 14 separate runs listed in the paper, fig. 7. He

then asserted that "Los Alamos" has confirmed the average result of 0.06 neut/sec. In fact, no such claim was made by Los Alamos. During the meeting I asked Howard Menlove about this claim and his response was that he lacked the statistics necessary to back the claim. On the other hand, the Gran Sasso collaboration confirms the Jones result at the higher value of 0.4 neut/sec!

The most troubling aspect of the cold fusion claim is its lack of reproducibility. Jones reports rates of from none to 10^{-23} fusions in his 14 runs. Texas A&M reports neutron production after the electrolysis current is turned off. They also report neutron quenching after the current is increased.

The most intriguing reports concern the observations of bursts of neutrons, detected by moderated ^{3}He detectors. Howard Menlove of LANL describes the most convincing evidence, using a set of ^{3}He detectors imbedded in polyethylene, developed for the materials safeguards program. Bursts are detected from cylinders containing Pd and Ti material under 40 atm of D_2 gas. The cylinders are cooled to liquid nitrogen temperatures and allowed to warm up. After an hour or so, when the temperature is near -30°, one sees, sometimes, a burst of neutrons. The success rate is nearly 10%, although some cylinders show no effect. Since a moderating assembly is used, no time structure can be inferred, although the burst length must be less than about 100 μsec, the lifetime in polyethylene.

A similar experiment was reported by Scaramuzzi of Frascati, although after three successful incidents he was unable to reproduce the effect. Scaramuzzi also reported, second hand, some burst seen at the Italian nuclear laboratory La Casaccia, in Rome. In this case, heating to 1000°C was necessary.

These effects may be related to fracturing phenomena which have been alleged by the Russians to be responsible for neutron and X-ray emissions. If the fracturing hypothesis is correct, this is not a cold fusion phenomenon, but a hot fusion reaction.

In summary, it seems clear to me that the diverse and chaotic phenomena reported cannot be reconciled as arising from a single source. The heat production is not consistent with particle production, which is feeble at best. Many of the particle detectors, while sensitive enough to dispose of the fusion rates demanded by the reported heat production, are not adequate to rule out neutron production at the Jones level of 10^{-23} fusions/deuteron pair/sec. The best neutron and charged particle detectors, however, set limits several orders of magnitude below the Jones result--namely about 10^{-25} fusions. These cannot be ignored unless black magic in the construction of a cell is invoked by Jones and his friends.

There is a possibility that the phenomenon of bursts is real. While the Frascati group claims no particular expertise in neutron detection, the LANL group is well-versed in this field. They assure us that their detectors are reliable and noise-free. They also are said to have seen a burst from an electrolytic cell, after the current is turned off. Only the crack theory can explain such results.

Neutron Detector Table I

Name/Type		Background (sec^{-1})	Efficiency	Merit=ε/B
BYU-Czirr	BC505 Scintillator + Li Glass	0.001	0.01	10
Texas A&M Wolf	NE213 PSD	0.003	0.003	1
Yale/BNL	NF213 PSD + TOF	0.0005	0.01	20
Gran Sasso	NE213 PSD	0.003	0.04	13
Bugey	NE320 Li Loaded	0.000005	0.027	5400
ORNL	NE213 PSD	0.001	0.005	5
Chalk River	^{3}He moderated	0.01	0.016	1.6
LANL - Menlove	^{3}He moderated	0.006	0.34	567

Proton/Triton Detector Table II

Name/Type	Background (sec^{-1})	Efficiency	Merit=ε/B
Ziegler-IBM Surface Barrier Silicon	0.0000578 (deduced fusion limit = 10^{-25})	0.25	4320
Meyers-Sandia Surface Barrier Silicon	0.0000347 (deduced fusion limit = 10^{-21})	0.0159	458

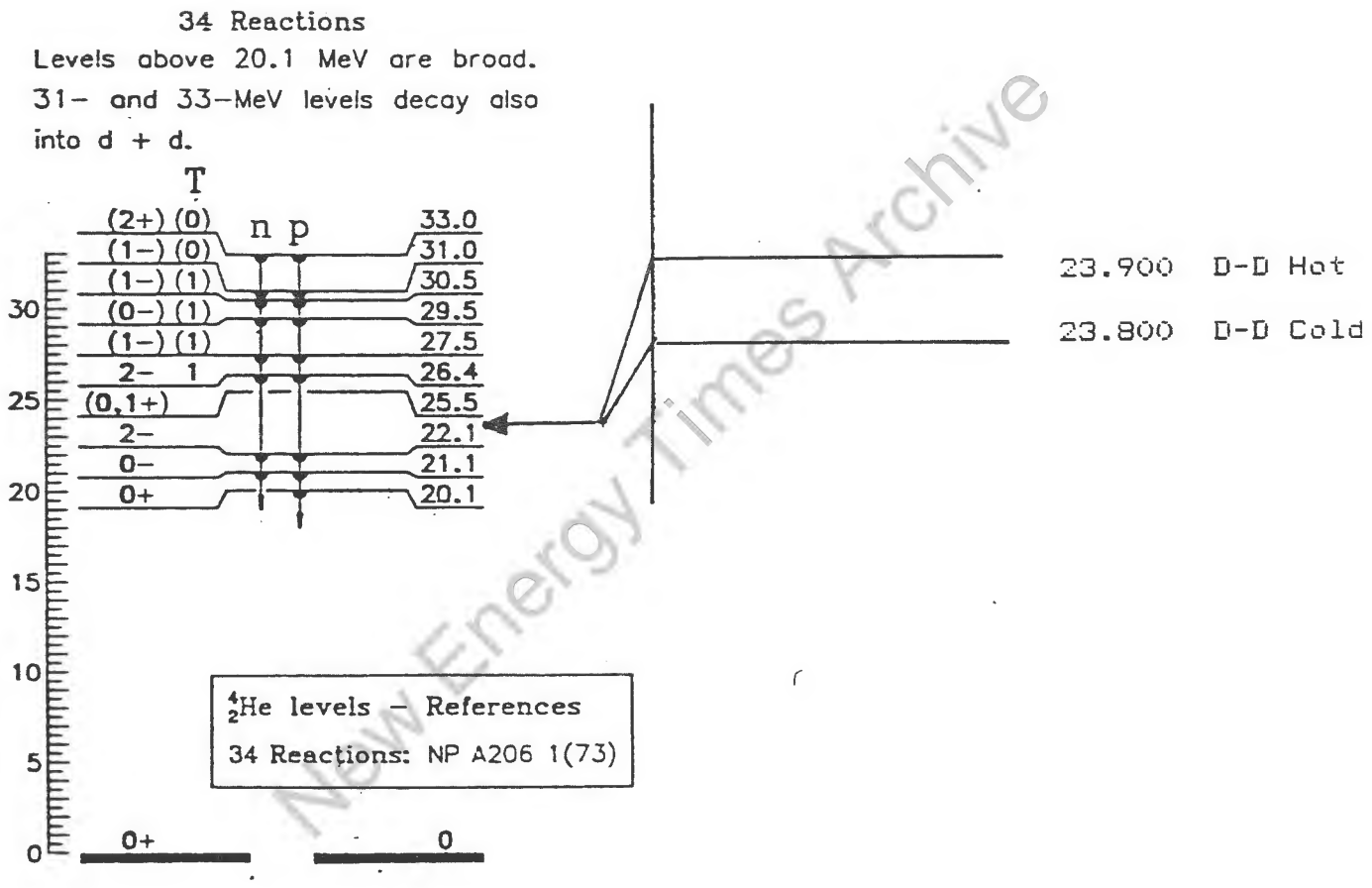


fig 1

PROPERTIES OF HYDROGEN-ISOTOPE FUSION REACTIONS AT LOW ENERGIES

A = 3	$D(p,\gamma)^3He$:	~50% S-wave, 50% P-wave at energies below 5 keV; P-waves more important at energies > 10 keV. Virtual state nearly at threshold in the $^2S_{\frac{1}{2}}$ channel.
A = 4	$D(d,p)^3H$:	86% S-wave (2^+ contr. > 0^+ contr.), 14% P-wave (mainly 1^-) (d,p) branch slightly enhanced overall, but (d,n) branch strongly enhanced for P-waves.
	$D(d,n)^3He$:	
	$D(d,\gamma)^4He$:	Mainly $^5S_2$(E2) capture at low energies [$^1D_2$(E2) at higher energies] when the D-state of ^4He is included. P-waves (E1, $\Delta S=1$) [mostly 1^-] become equally important above ≈ 100 keV.
A = 5	$^3H(d,n)^4He$:	> 99.9% S-wave (almost entirely $3/2^+$).

fig 2

REACTION CONSTANTS

$$A_0 = \left(\frac{S_0[\text{keV-b}]}{\mu[\text{amu}]}\, 1.40385\times10^{-18}\right)\left[\frac{\text{cm}^3}{\text{s}}\right]$$

Reaction	S_0 [keV-b][a]	A_0 [$cm^3 s^{-1}$][a]	S_0 [keV-b][b]	A_0 [$cm^3 s^{-1}$][b]	
T(d,n)	1.158×10^4	1.348×10^{-14}	1.1×10^4	1.3×10^{-14}	
D(d,p)	55.97	7.805×10^{-17}	53	7.5×10^{-17}	←
D(d,n)	53.61	7.476×10^{-17}	53	7.5×10^{-17}	←
D(p,γ)			2.5×10^{-4}	5.2×10^{-22}	
D(d,γ)			2.22×10^{-7}	3.1×10^{-25}	←

[a] Calculated from R-matrix parameters.

[b] Taken from Fowler, Caughlin, and Zimmerman, *Annual Reviews of Astronomy & Astrophysics* 5, 525 (1967), (A_0 given by Koonin).

fig 3

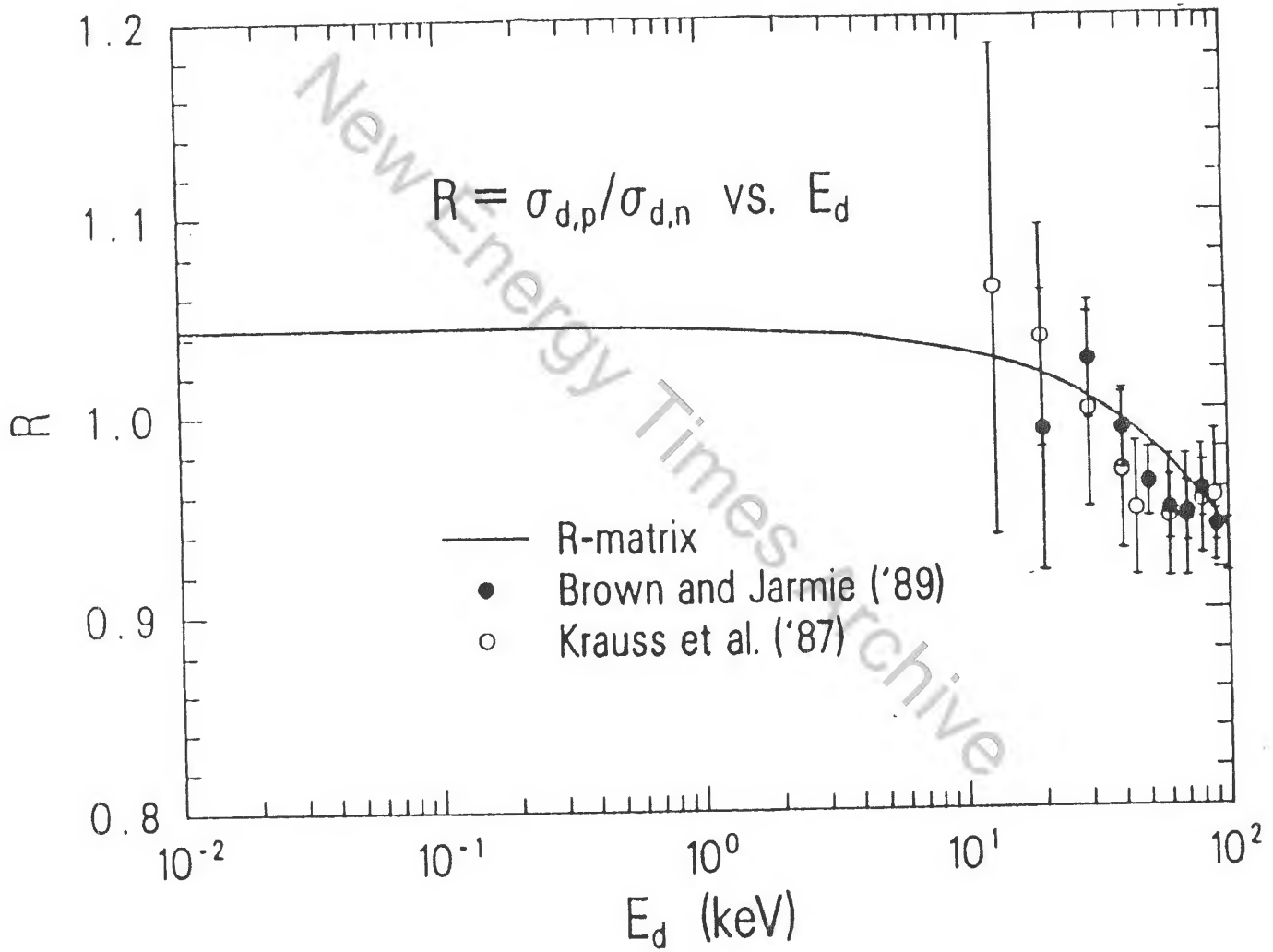


fig 4

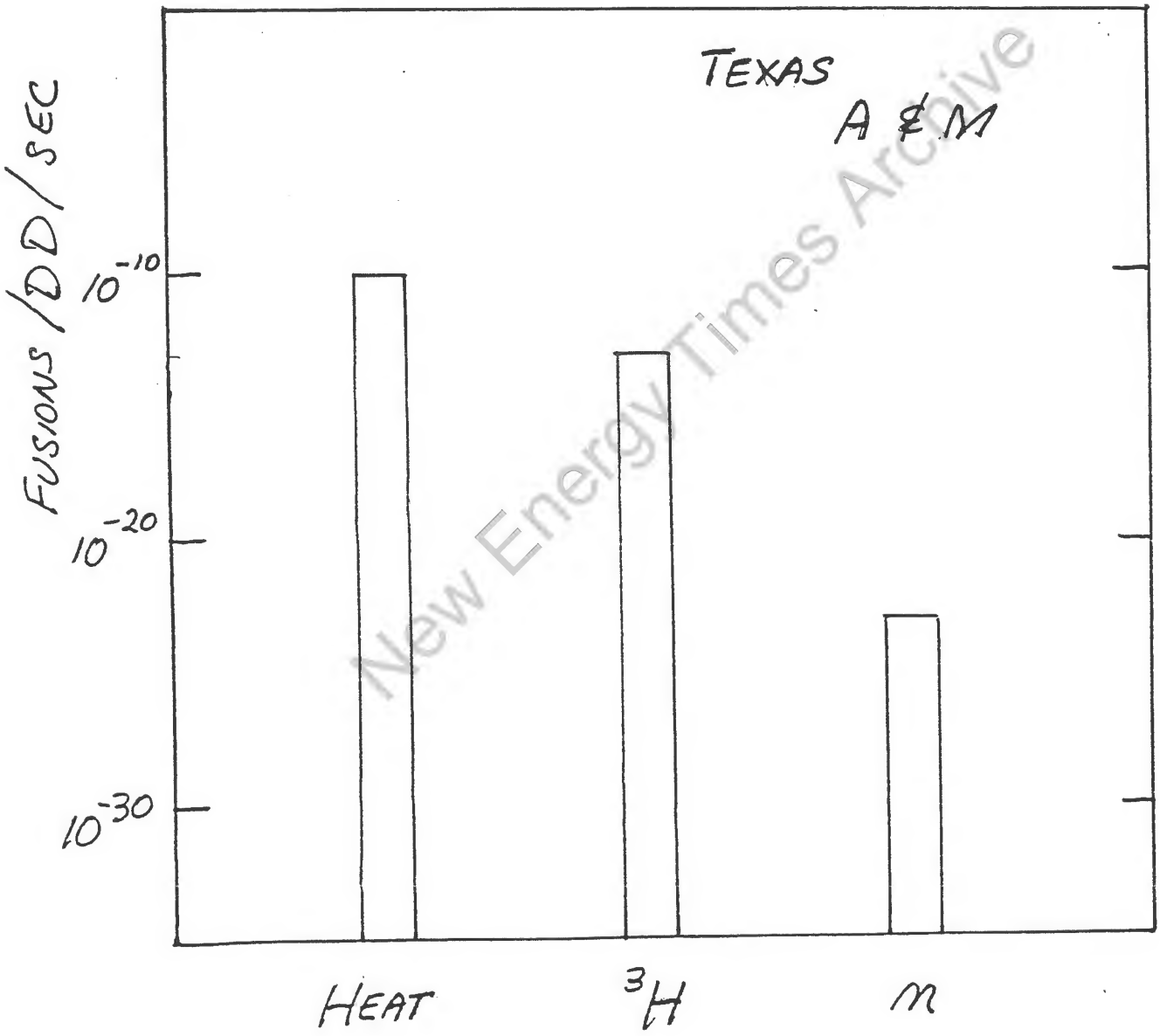


fig 5

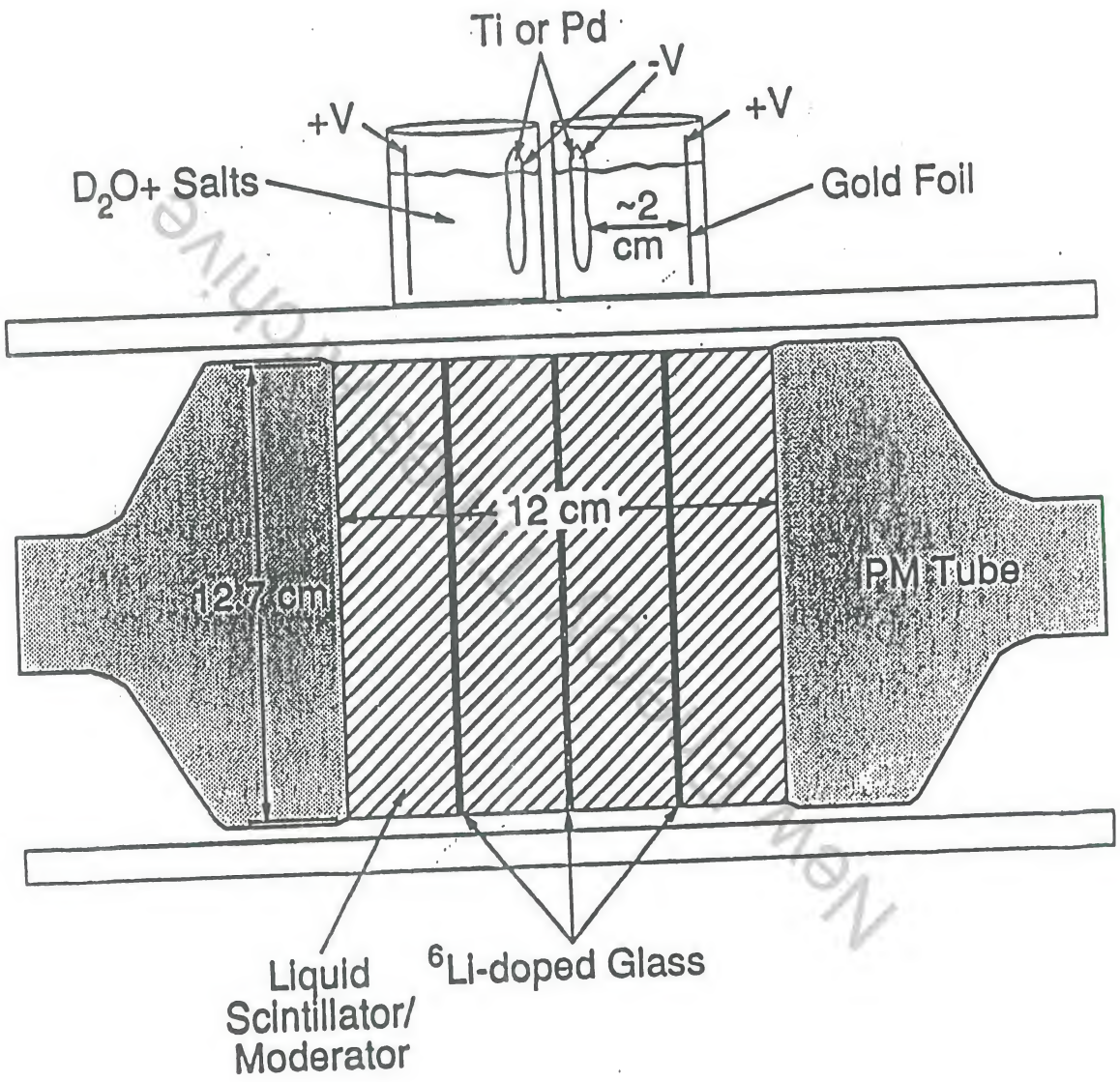

Ti or Pd
-V
+V
+V
D_2O+ Salts
Gold Foil
~2 cm
12.7 cm
12 cm
PM Tube
Liquid Scintillator/ Moderator
^{6}Li-doped Glass

Fig.1

fig 5

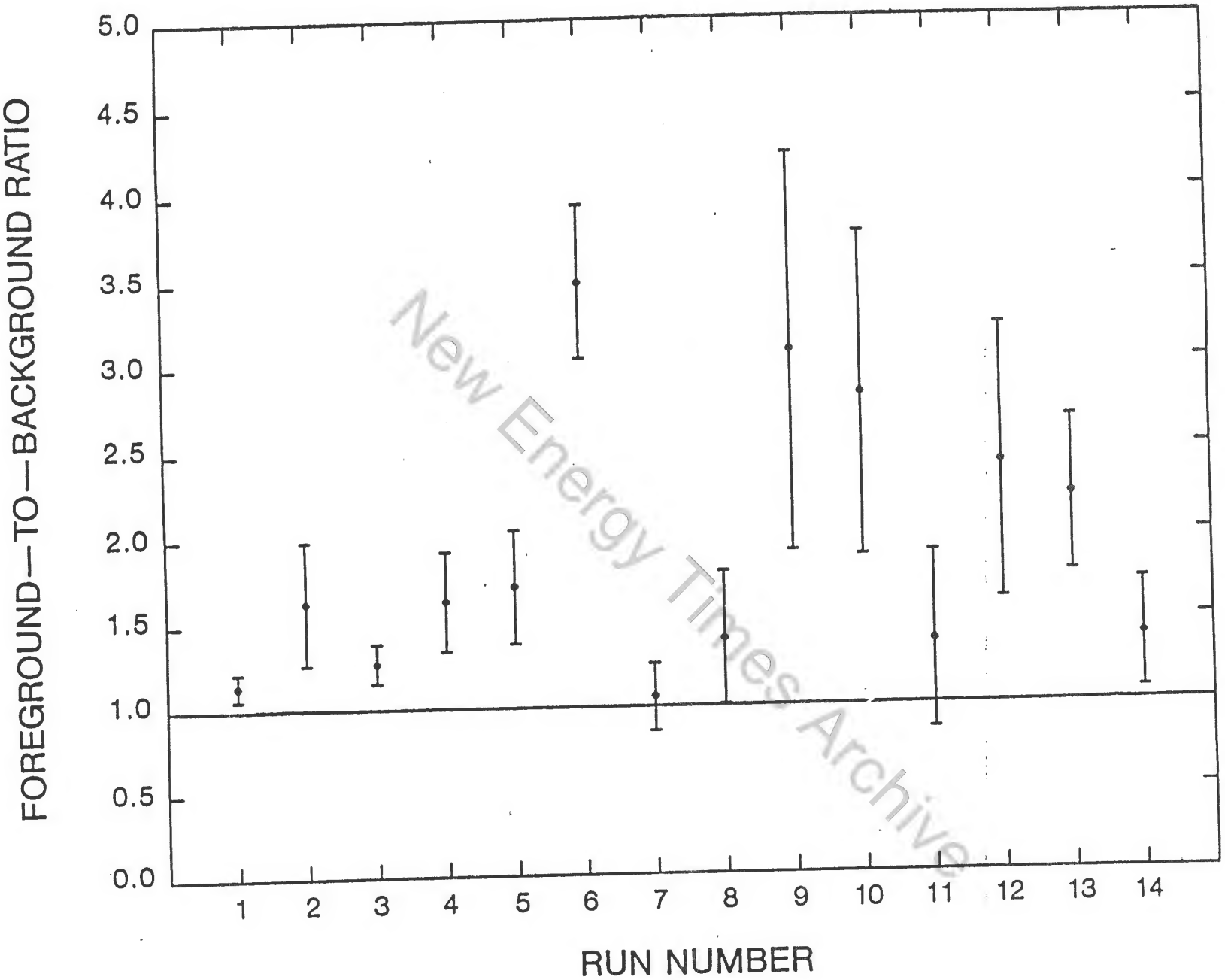
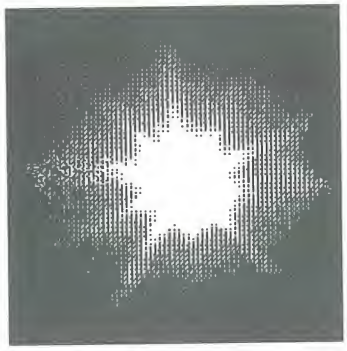


Fig. 7



WORKSHOP ON COLD FUSION PHENOMENA

MAY 23-25, 1989
SANTA FE, NEW MEXICO

AGENDA

Sponsored by Los Alamos National Laboratory
and the U.S. Department of Energy

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AGENDA

WORKSHOP ON COLD FUSION PHENOMENA

May 22–25, 1989

SWEENEY CENTER, SANTA FE, NM

MONDAY, MAY 22

Workshop participants arrive in Santa Fe

4:00 – 8:00	Registration and badge issue at Eldorado Hotel—Hospitality room available at Eldorado Hotel	

TUESDAY, MAY 23

7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 8:30	Late Registration	
8:30 – 9:00	Preliminary Remarks	Reed J. Jensen
–	Welcome	Sig Hecker
–	Introduction of Workshop	Norman Hackerman
9:00 – 12:00	First Plenary Session (A)—**Integrated Experiments** Moderator: **Reed J. Jensen** Los Alamos National Laboratory	
9:00 – 9:30	Evidence for Excess Heat Generation Rates During Electrolysis of D_2O in LiOD Using a Palladium Cathode – A Microcalorimetric Study (Invited Talk)	A.J. Appleby, S. Srinivasan, O.J. Murphy, C.R. Martin Texas A&M
9:30 – 9:50	Neutron Emission and the Tritium Content Associated with Deuterium Loaded Palladium and Tritium Metals	K.L. Wolf, N. Packham, J. Shoemaker, F. Cheng, D. Lawson Texas A&M
9:50 – 10:20	BREAK – Refreshments Available	

10:20 –	Electrochemical "Cold Nuclear Fusion" Attempts at IPP	G.A. Wurden LANL H.S. Bosch, J. Gernhardt, G. Janeschitz F. Karger, J. Perchermeier Max Planck Institut für Plasma Physic FR Germany
10:40 –	Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes	D. Albagli, V. Cammarata, M. Schloh, M.S. Wrighton X. Chen, C. Fiore M. Gaudreau, D. Gwinn, P. Linsay, S.C. Luckhardt, R. Parker, R. Petrasso K. Wenzel, R. Ballinger I. Hwang MIT
11:00 –	In Search of Nuclear Fusion in Electrolytic Cells and Metal/Gas Systems	D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden W.G. Cross, A. Arjena, A.M. Lone, D.C. Tennant, W.J.L. Buyers Chalk River Labs Ontario, Canada
11:20 –	LUNCH/POSTER SESSION	
1:30 – 5:00	Second Plenary Session (B)— **Integrated Experiments** (Cont'd) Moderator: **Fred Morse** Los Alamos National Laboratory	
1:30 –	Search for Neutrons from Cold Fusion in Pd-D	R.S. Raghavan, L.C. Feldman M.M. Broer, J.S.Kraus, A.C. James, D.W. Murphy AT&T Bell Labs
1:50 –	Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in D_2O	Nathan S. Lewis, Charles A. Barnes Cal Tech
2:10 –	Search for Fusion in Deuterated Transition Metals: Dynamical Pressures Above 1 Megabar	F.M. Mueller, K.A. Johnson, W.J. Medina, A.R. Mantheia, C.L. Talcott, E.K. Storms J.W. Shaner, B.L. Freeman J.E. Vorthman, M.M. Fowler LANL

2:30 –	Tests for "Cold Fusion" in the $Pd\text{-}D_2$ and $Ti\text{-}D_2$ Systems at 350 MPa and 195-300 K	J.G. Blencoe, M.T. Naney, D.J. Wesolowski ORNL
2:50 –	Measurements of Heat, Neutron and γ Flux Induced by μ Stopped in Deuterium Saturated Targets	M.Chen, S. Steadman, C.Fiore, M. Gaudreau, S. Luckhardt, R. Parker, R. Crooks, M. Schloh, D. Albagli, V. Cammarata, M. Wrighton MIT R. Debbe, D. Lowenstein BNL
3:10 –	Electrochemical Experiments in Cold Nuclear Fusion	J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan, A.D. Marwick IBM Rsch. Div., Thomas J. Watson Research Center
3:30 –	BREAK – Refreshments Available	
	Physics of Fusion Reaction	
4:00 –	Nuclear Reactions and Screened-Coulomb Fusion Rates	G.M. Hale, R.D. Smith, T.L. Talley LANL
4:20 –	Molecular Dynamics Simulation of $PD_{1.1}$: How Close Can Deuterons Get?	Peter M. Richards SNL
4:40	Conditions Leading to the Production of Cold Fusion Neutrons	M. Gajda, G. Harley, J. Rafelski Univ. of Arizona
5:00 – 5:30	BREAK – Walk to Eldorado Hotel	
5:30 – 7:00	Reception at Eldorado Hotel	
7:00 – 7:30	Return to Sweeney Center	
7:30 – 9:30	Discussion Period with Presenters	J. O'M. Bockris

WEDNESDAY, MAY 24

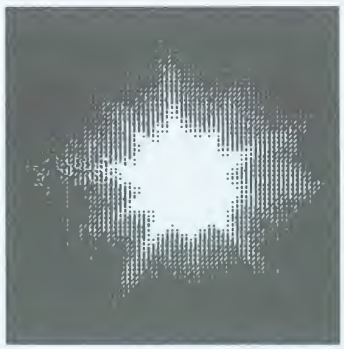
7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 12:00	Third Plenary Session (C)— **Neutron- & Gamma-Ray Spectroscopy** Moderator: **C. A. Barnes** Cal Tech	
8:00 –	Cold Nuclear Fusion in Condensed Matter: Recent Results and Open Questions (Invited Talk)	S.E. Jones BYU

8:30 –	Experimental Evidence for Cold Nuclear Fusion in a Measurement Under the Gran Sasso Massif	A. Bertin, M. Bruschi, M. Capponi, S. DeCastro, U. Marconi C. Moroni, M. Piccinini, N. Semprni-Cesari, A. Trombini, A. Vitale, A. Zoccoli Instituto Nazionale Di Fisica Nucleare Italy J.B. Czirr, G.L. Jensen S.E. Jones, E.P. Palmer BYU
8:50 –	The Measurement of Neutron Emission from Ti Plus D_2 Gas	H.O. Menlove, M.M. Fowler E. Garcia, A. Mayer, M.C. Miller, R.R. Ryan LANL S.E. Jones BYU
9:10 –	Neutron Emission from a Titanium-Deuterium System (Invited Talk)	A.De Ninno, A. Frattolillo, G. Lollobattista, L. Martinis, M. Martone, L. Mori S. Podda, F. Scaramuzzi Centro Ricerche Energia Frascati Italy
9:40 –	Upper Limits on Emission Rates of Neutrons and Gamma-Rays from "Cold Fusion" in Deuterided Metals (Invited Talk)	M. Gai, S.L. Rugari, R.H. France, B.J. Lund, Z. Zhao Yale A.J. Davenport, H.S. Isaacs, K.G. Lynn BNL
10:10 –	BREAK – Refreshments Available	
10:40 –	Lack of Neutron and Gamma Radiation from PPPL's Cold Fusion Experiments	H.Hsuan, D. Manos, S. Cowley, R. Motley, L. Roquemore, T. Saito, J. Timberlake, W. Ayeres, T. Bennett, M. Bitter E. Cecil, S.C.J. Cuthbertson, H.F. Dylla, H. Furth, L. Grisham, H. Hendel, K. Hill, R. Kulsrud, D. Meade, S. Medley, D. Mueller, E. Nieschmidt, R. Shoemaker, J. Thomas Princeton University
11:00 –	An Attempt to Measure Characteristic X-Rays from Cold Fusion	R. Fleming,F. Donahue, S. Mancini,G. Knoll, B. Heuser Univ. of Michigan

11:20 –	LUNCH/POSTER SESSION	
1:30 – 5:00	Fourth Plenary Session (D)— **Calorimetry** Moderator: **Anthony Turkevich** University of Chicago	
1:30 –	Title Unknown at Printing (Invited Talk)	R.A. Huggins Stanford University
2:00 –	Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells	N.A. Godshall, E.P. Roth, M.J. Kelly, T.R. Guilinger, R.I. Ewing SNL
2:20 –	The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations	A.E. Pontau SNLL
2:40 –	Calorimetric Measurements on Electrochemical Cells with Pd-D and Pd-H Cathodes	L. Redey, K.M. Myles, D. Dees, M. Krumpelt, D.R. Vissers ANL
3:00 –	Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis	D.E. Stilwell, M.H. Miles Naval Wpns. Cntr.
3:20 –	BREAK – Refreshments Available	
	Physics of Fusion Reactions–II	
4:00 –	Seven Chemical Explanations of the Fleischmann-Pons Effect	J.O'M. Bockris, N. Packham, O. Velev, G. Lin, M. Szklarzcyck, R. Kainthla Texas A&M
4:20	Evidence Against Condensed Matter Fusion Induced by Cosmic-Ray Muons	K. Nagamine, T. Matsuzaki, K. Ishida, S. Sakamoto, Y. Watanabe, M. Iwasaki, H. Miyake, K. Nishiyama, H. Kurihara, E. Torikai, T. Suzuki, S. Isagawa, K. Kondo University of Tokyo
4:40 –	DINNER/POSTER SESSION	
5:30 – 7:00	Optional, No-Host Buffet at Eldorado Hotel	
7:00 – 7:30	Return to Sweeney Center	
7:30 – 9:30	Discussion Period with Presenters	M. Broer

THURSDAY, MAY 25, 1989

7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 12:00	Fifth Plenary Session (E)— **Applicable Condensed-Matter Physics, Applicable Electrochemistry, Analytical Chemistry of Appropriate Products** Moderator: **Johann Rafelski** University of Arizona	
8:00 –	PAC Studies of Electrolytically Charged Metal Cathodes	G.S. Collins, S.L. Shropshire, Jiawen Fan Washington State Univ.
8:20 –	Interaction of Deuterium with Lattice Defects in Palladium	F. Besenbacher,B.B. Nielsen, S.M. Myers,P. Nordlander, J.K. Norskov University of Aarhus Denmark
8:40 –	Search for Cold Fusion in Superstoichiometric Palladium Deuteride Using Ion Implantation	S.M. Myers,D.M. Follstaedt, J.E. Schirber,P.M. Richards SNL
9:00 –	Tritium Enrichment in the Electrolysis of D_2O	J. Bigeleisen State Univ. of NY Stony Brook, NY
9:20 –	Nuclear Fusion from Crack-Generated Particle Acceleration	F.J. Mayer,J.S. King, J.R. Reitz FJM Assoc., Univ. of Michigan Ford Motor Rsch. Lab
9:40 –	Search for 0.8 MeV ^{3}He Nuclei Emitted from Pd and Ti Exposed to High Pressure D_2	S.W. Barwick,P.B. Price, W.T. Williams UC–Berkeley
10:00 –	BREAK – Refreshments Available	
10:30 –	Workshop Summary/Wrap-Up	R. Schrieffer, N. Hackerman
12:00 –	Workshop Concludes	



WORKSHOP ON COLD FUSION PHENOMENA

MAY 23-25, 1989
SANTA FE, NEW MEXICO

MEETING ABSTRACTS
Session A

Sponsored by Los Alamos National Laboratory
and the U.S. Department of Energy

EVIDENCE FOR EXCESS HEAT GENERATION RATES DURING ELECTROLYSIS OF D_2O IN LiOD USING A PALLADIUM CATHODE - A MICROCALORIMETRIC STUDY

Supramaniam Srinivasan*, Young Jin Kim*,
Oliver J. Murphy*, Charles R. Martin** and A. John Appleby *

*Center for Electrochemical Systems and Hydrogen Research
Texas Engineering Experiment Station
and
**Department of Chemistry
Texas A&M University
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The "cold fusion" announcement by Professors Martin Fleishmann and Stanley Pons on March 23, 1989, evoked great excitement and was a stimulation for scientists all over the world to reproduce their results. Microcalorimetric investigations were commenced in our laboratory with the objective of measurement of the excess heat generation rates reported by these scientists. The rationale for selection of the microcalorimetric techniques were: (1), the high sensitivity of microcalorimeters using thermoelectric measuring principles; (2), the successful use of microcalorimeters for measurement of heat generation rates in the 1μW to 8W range to predict self discharge rates of, for example, pacemaker batteries with predicted lifetimes of over ten years; and the rates of slow corrosion processes; and (3), the possibility of using small Pd electrodes (short, thin wires, small spheres) to minimize (i) the time required for maximum absorption of deuterium by electrochemical charging; (ii) the charging input power; and (iii) the consequent low input power requirements at the high current densities at which anomalous heating was observed.

A Tronac(Model 350) Microcalorimeter, refurbished by Hart Scientific Instruments, was used in this work. The basic components of this equipment are (1) stainless steel test and control cells (5 x 5 x 1 cm^3) which are snugly fitted into an aluminum block sink; (2) water reservoir, external to the aluminum block maintained at a constant temperature; and (3) thermoelectric sensors surrounding the test and control cells. The measurements are based on the Seebeck effect: A voltage develops between the hot (test) and cold (control) junctions, which is a measure of the heat flux.

Several tests and control experiments were carried out to determine the excess heat generation rates. These experiments consisted of:

1. Control Experiment - charging of Pd wire (0.5 mm diameter, 1 cm length) in 0.1M LiOH at 60 mA/cm^2 for two days and then increasing the current density for D_2O electrolysis to 600 mA/cm^2 for four days, continuously recording the heat generation rate;

2. Control Experiment - Recording of heat generation rates during electrolysis of D_2O in 0.1M LiOD on a Pt cathode (wire with same dimensions as in Experiment 1).

3. Test Experiment - similar to Experiment 1, but conducted in 0.1M LiOD. In this equipment, the heat generation rates were also recorded when the current density was increased from 0.6 A/cm^2 to 1.0 A/cm^2 and then decreased to 0.3 A/cm^2.

The results of these experiments may be summarized as follows:

1. Excess heat generation rates were observed only in the test experiment (Experiment #3) and not in the control experiments (Experiments #1 and #2).

2. The rate of excess heat generation was 19 W/ml of Pd, close to the value (26 W/ml of Pd) reported by Fleischmann and Pons. The observed heat generation rate showed no increase when the current density for electrolysis was increased from 0.6 to 1 A/cm^2 but decreased to 14 W/ml of Pd when the current density was lowered to 0.3 A/cm^2.

3. The results of the two control experiments confirm that the rates of recombination of H_2 or D_2 with O_2 are negligible and cannot account for the excess heat generation rate in the test experiment.

Electrochemical "Cold Nuclear Fusion" Attempts at IPP

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Abstract

Following the report of Pons and Fleischmann, we (The Bavarian Bubble Bottle Team) have attempted to reproduce their claims of cold nuclear fusion, and failed. We note that our measurements would not be able to detect neutrons at the level of Jones *et al.* Three experiments were conducted without any signs of neutrons, tritium or gammas above backgrounds, and within ±5% accuracy calorimetry, no excess heating. Intrinsic tritium, differing from each D_2O bottle tested, was however observed.

The third, and most significant attempt used a 22 gram, 10 cm^2, cast (vacuum melted by an e-beam) palladium piece, which was electrolytically loaded with deuterium (99.75% purity D_2O, 0.11 M LiD, Pt mesh anode) at current densities of 200-250 mA/cm^2 for a period of 21 days. Current, voltage, water bath (well-stirred) and air temperature were monitored continuously with a strip chart recorder. The fully covered 170 ml central cell did not partition the electrolysis products, all calorimetry was done in steady state, (bath time constant 100 minutes), and air flow across the 1 liter water bath was kept constant. No isolation Dewar was used. Measurements of the actual temperature(s) directly in the center cell showed strong thermal gradients ($3-4°C$), so calorimetric measurements are only relevant for the well-stirred water bath/air temperatures (typically 45 and 26°C, respectively). An absolute resolution of better than 200 mW, out of 20 Watts typical input power, was obtained. The equilibrium temperature rise of the water bath was strictly linear with input power, calculated from $P_{in} = I * (V - 1.54v)$. A Kapton encapsulated 40 Ohm strip resistor was used in the water bath for reference ohmic input measurements. Fast reductions in current density, after waiting for a new thermal equilibrium, yielded nothing unusual. A BF_3 thermal neutron counter, (calibrated efficiency of 1 count/370 neutrons from the same location as the cell, backgrounds of 0.05 counts/sec, with 12 cm polyethylene moderator and a Cd shield), as well as a moderated Li^6I neutron detector, a large high-resolution, high efficiency (170 cm^3) GeLi gamma detector, a 2" NaI detector, and a proportional counter were used to look for radiation. Gamma backgrounds from K^{40}, Bi^{214} and Tl^{208} (Thorium decay in concrete), were easily seen in pulse height spectra. Backgrounds at our second floor location were 120 mrem/year gammas, and 10 mrem/year thermal neutrons, as measured by a Berthold LB1026 Radiation Monitoring system. No special shielding precautions against cosmic rays were used. A 4 Megawatt swimming pool nuclear reactor, 600 meters away from our building, was one of our additional background considerations! Tritium was measured in the electrolyte, D_2O samples, and H_2O (both with and without the LiD solute). A model 2260XL Tri-Carb Liquid Scintillation Analyzer by Canberra-Packard was used, with the old ($\geq$ 15 years) Merck heavy water yielding 210 dpm/ml from one vial, and 9.9 dpm/ml from another used for refilling. By contrast the LiD dissolved in pure H_2O (unneutralized) gave 6.6 dpm/ml. The cell was replenished with D_2O at a rate averaging 16 ml/day. The electrolyte after 19 days of operation measured 150 dpm/ml. In comparison, the D_2O from another bottle (with same Merck #, and purchased at the same time!) used in our first 14 hour experiment had 750 dpm/ml. Pulse height analysis suggests that true Tritium decay signals are present, and chemical fluorescence in the "cocktail" was not important (although measurable). Tritium can reasonably be explained from that originally present in the various D_2O flasks.

The experiment was terminated on April 28, by throwing the loaded palladium sample directly into liquid Nitrogen, immediately next to the bare BF_3 counter (backed by 25 cm of moderator), in order to attempt one of the Italian ENEA neutron production variants. No neutrons (sensitivity of 5 n/sec equivalent source strength) above backgrounds were seen, while counting for one hour, and also none while the piece warmed to room temperature over the next hour. Postmortem analysis of the darkened, hardened Pd piece showed large crystal grains (up to 2mm×2mm), and continuing evolution of gas bubbles at the grain boundaries even four days after the experiment was ended.

NEUTRON EMISSION AND THE TRITIUM CONTENT ASSOCIATED WITH DEUTERIUM LOADED PALLADIUM AND TRITIUM METALS*

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An experimental investigation has been conducted on samples of Pd and Ti which were loaded with deuterium through the electrolysis of D_2O and by absorption of D_2 gas. In approximately 200 experiments on 25 samples, statistically significant evidence for neutron emission was obtained in two separate experiments from one Pd-Ni electrolysis cell. Observed rates of 3-4 times the background rate of 0.8 neutrons/min (0.4-2.5 MeV) correspond to a 2.5 MeV neutron source strength of 50 neutrons/min over a period of 1-2 hours.

A 3" x 5" NE213 liquid scintillator coupled to a 5"-diameter RCA 8854 phototube was used for an overall efficiency of 5% for 2.5 MeV neutrons. Pulse shape discrimination (PSD) was used for n/γ discrimination. Cosmic ray rejection was provided by the PSD and by 2' x 4' x 1/4" plastic scintillator paddles. Antennas and the PSD were used for external noise rejection. The neutron detector was shielded from the heat produced by electrolytic cells and the temperature was monitored. Data were acquired with a CAMAC-based LeCroy 2280 system interfaced to an 80386 computer.

The presence of 5×10^{12} tritium atoms in the solution of the electrolysis cell was determined several days after the neutron production runs. Tritium detection was accomplished with a pair of low-noise EMI 9954 phototubes coupled to a 1 cm x 1 cm x 3 cm cell. Neutralized samples were mixed with a water soluble liquid scintillator for an efficiency of 30%, in coincidence mode. Energy spectra were compared to tritium standards for the efficiency and for identification through slope and end point determinations. Tritium content of the cell before neutron production is not known.

*This work supported by the U. S. Department of Energy under Grants DE-FG05-86ER40256 and DE-FG05-88ER40437 and by The Robert A. Welch Foundation.

Say 20 cm^3 -- so 2.5×10^{11} T/ml

T ≈ 20 yrs ~ 6×10^8 sec

so R = 400 dps/ml = 24,000 dpm/ml

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May 23–25, 1989
Santa Fe, New Mexico

Search for Neutrons from Cold Fusion in Pd–D

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We report on a search for neutrons from dd fusion in Pd rods loaded electrolytically with deuterium. Three Pd rods were used: 1) 0.125 dia. x 9 cm long, drawn and cold worked; 2) 0.125 dia. x 9 cm long, drawn and annealed; 3) 0.41 dia. x 8 cm long, cast, drawn and annealed. The rods were held in two electrolytic cells (D_2O (99.5% D)+ 0.1 M LiOD, current density 53 mA/cm^2) and placed before a 12.5 dia. x 12.5 cm NaI(Tl) detector with 5 cm of polyethylene (PE) moderator interposed. A pair of plastic scintillator plates above and below the NaI(Tl) vetoed cosmic muons. The apparatus was housed within 10 cm thick PE surrounded on the outside with Pb and borax. Fusion neutrons are moderated inside the PE housing, creating a slow neutron gas that can be detected by two γ–ray producing reaction signals: (1) n–capture by protons in the PE (2.224 MeV γ); (2) ^{23}Na and ^{127}I n–capture γ–rays in the range 3.5–7 MeV. The latter, produced inside the NaI(Tl), is the more sensitive signal. The background in this region, mostly due to cosmic rays, is far less than the background below 2.62 MeV, which is dominated by natural radioactivity. Therefore our results are insensitive to ambient natural radioactivity. From the overall n detection efficiency (measured with an Am–Be source immersed in D_2O(LiOD) at the counting position) and the observed background limit, we deduce that neutron production at the rate of $\sim$ 0.1 n/sec in the cells can be detected. In a four–week measurement we observe <0.007 n/sec/g Pd, (0.4 cm dia. rod) compared to 2.6x10^{3}n/sec/g Pd, claimed in recent work[1] for a similar Pd rod. Our result implies <2.2x10^{-24} (ddn) fusions/dd pair/sec in our Pd electrode, as compared to $\sim$ 10^{-23} (ddn) fusions/dd pair/sec observed by Jones et al[2] in a Ti electrode.

1. M. Fleischmann and B.S. Pons, J. Electroanal. Chem. **261**, 301(1989).
2. S.E. Jones et al, Nature **338**, 737(1989).

Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in D_2O

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We report the results of our work on cold fusion using palladium. We have used extremely sensitive neutron, gamma ray, and photo counters, and can place strict upper limits on the flux of expected nuclear products emitted from charged Pd cathodes. Liquid scintillation counting has been used to measure tritium production, which was found at background levels for extended periods of time. However, a subtle chemical interference that generates chemiluminescence has been shown to yield tritium signals and lead to overestimates of the fusion yield based on tritium production. We have also performed accurate, calibrated calorimetry, and have identified several serious errors that can make the measurements appear to show excess power production. When these common errors are eliminated, a correct energy balance is obtained. We have used cold-worked Pd, recast Pd, Pd thimbles, and Pd wires over a variety of pH values and for a variety of activation times. We will also discuss the calorimetry experiments performed by the Utah researchers, will explain their calculations to the physics community,and will clearly state the assumptions and corrections implicit in the Utah calculations.

SEARCH FOR FUSION IN DEUTERATED TRANSITION METALS: DYNAMICAL PRESSURES ABOVE 1 MEGABAR

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One can conceive a number of possible solid state or metallurgical mechanisms to produce enhanced fluctuation fusion rates in Deuterated Metals, such as Coulomb Screening, Crowdions, Dislocations, Crack Propagation, Shear Banding, Vacancy and Void Filling, Grain Interstices, Twinning, Tweeding and Surface Reconstruction, Dynamically Shrinking, through pressure, a transition metal lattice containing Deuterium probes all of these possible mechanisms simultaneously to some degree.

A Cylindrical Shock Experiment was performed on Deuterated Pd (0.3 gm) and Ti (0.1 gm) foils using a fully recoverable, high pressure, and well tested design. Four gm of Zn was also inserted in the experimental chamber as a post shot neutron radiochemical detector. The system was pressure tested and its free volume was measured. The system was then cleaned to remove gas contaminants, surface poisons or deuterium transfer inhibitors. The system was then back loaded with deuterium at room temperature initially at a pressure of 50 psi which dropped to a pressure of 30 psi of Deuterium gas. The observed uptake rates showed that both foils deuterated to about 0.7 D/M for Pd and about 0.7 for Ti. The sample container was removed from the loading system, maintaining gas tightness, and inserted into the high explosive configuration. The entire system was then subject to a Dynamical Shock Pressure of greater than 0.1 Tera Pascals. Prompt Neutron Detectors were placed behind protecting sandbags and Pb bricks in the close proximity of the experiment. Post Shot radiochemical analysis was also performed. The results showed that less than 10^4 neutrons were generated. No increased neutron flux over background was detected during the several microseconds of Dynamical Pressure on the deuterated foils. We conclude that whatever mechanisms are possible to enhance fusion rates in deuterated transition metals, they were not present at the detection level and pressures of this experiment.

Tests for "cold fusion" in the $Pd-D_2$ and $Ti-D_2$ systems at 350 MPa and 195-300K

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Experiments are in progress on the $Pd-D_2$ and $Ti-D_2$ systems at 350 MPa, 195-300K, to investigate the possibility that "cold fusion" occurs in high D/metal phases generated by pressurization with D_2 gas. Reactions between high-purity Pd or Ti and D_2 are being monitored using BF_3 neutron detectors and thermocouples. The neutron detector array has an efficiency of approximately 6%, as determined using a ^{252}Cf source. The pressure vessel and neutron detectors are immersed in a water bath thermostated at 300K. A type-K thermocouple in contact with the Pd or Ti sample is compared with a reference type-K thermocouple also housed in the vessel and located approximately 10 cm above the sample. The neutron flux, gas pressure, sample and reference thermocouples and bath temperature are continuously monitored at time intervals ranging from 6 seconds to 5 minutes.

Experiments completed to date in the $Pd-D_2$ system at 300K have shown no neutron flux significantly above background (9.5±0.5 counts/min.), and no sustained heat production has been detected.

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Measurements of Heat, Neutron and γ Flux Induced by μ Stopped in Deuterium Saturated Targets

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Abstract. We use small scintillation hodoscopes to define a pencil-size 80 MeV/c μ beam at BNL to stop negatively charged μ's inside Pd and Ti targets saturated with deuterium/hydrogen. Heat, neutron and γ flux produced from the targets as functions of the number of stopped muons are measured with calorimeters, BF_3/He_3 counters and NaI crystals respectively. The relative rates with/without stopping muons are measured using cast thin Pd rods in an ongoing electrochemical cell similar to that used by Pons and Fleishmann. The absolute rates are measured in targets made of thin foils. The background is calibrated both with targets in the beam but without deuterium/hydrogen and with targets saturated with deuterium but without muons stopped in them. We also search for any excess helium produced inside the target material. The results are compared with theories which claim cold fusion is induced by cosmic ray muons.

Abstract: 1) ELECTROCHEMICAL EXPERIMENTS IN COLD NUCLEAR FUSION, by J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan and A.D. Marwick, IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, NY 10598 USA. Recently, two scientific papers have reported positive detection of nuclear radiation from similar electro-chemical cells operating with deuterated water. Fleischmann and Pons have observed gamma rays at 2.2 MeV at a rate of about 4000/cc-s, and if the heat they observe is due to unobserved nuclear fusions, they have a fusion rate of about 10**12 fusions/cc-s (the subscript "cc" refers to the volume of Pd cathode used). In an independent work, Jones et al. have reported detecting 2.4 MeV neutrons at a rate of 0.7 neutrons/cc-s from an electrolytic cell.

We have experimented with similar electrolytic cells and have looked for energetic charged particles which are characteristic of nuclear fusion reactions. We report on six variations of cell, with an upper limit of 0.005 detected particles/cc-s. Within background statistics, we observe zero nuclear fusions. (Submitted to Physical Review Letters: 18 April, 1989)

2) Experimental reports of cold nuclear fusion continue to raise questions, e.g. in regard to details of stirring during calibration of the cells in which temperature rise is used to infer heat generation. Other possible problems include the assumption that power input is the product of time averages of voltage and current applied to the cell, whereas it is the time average of the instantaneous product. Monitoring the reaction cells for electromagnetic signals would help to determine whether "arcs and sparks" play a role in the generation of the nuclear particles observed in some experiments. Comments along these lines, updated to reflect experiments as of the time of presentation, may help in evaluation and to focus further experimental work.

Nuclear Reactions and Screened-Coulomb Fusion Rates

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We discuss properties of nuclear reactions (branching ratios, reaction constants, etc.) between hydrogen isotopes from the standpoint of recent R-matrix calculations. These calculations predict, for example, quite different branching ratios for the d+d reactions when they are initiated by S-waves than when they are initiated by P-waves. We will also give a more speculative discussion of the constraints on possible non-radiative electromagnetic transitions that could occur for the d-d and p-d reactions in the metal lattice.

When R-matrix theory is used to include nuclear effects at small distances in the calculation of fusion rates, the rate expression exhibits a more complex interplay of the short-ranged (nuclear) and long-ranged (screened Coulomb) forces than does the familiar separable form,

$$\lambda = A_0 |\Psi(r=0)|^2 ,$$

to which the R-matrix expression reduces if the appropriate approximations are made. Using the latest nuclear R-matrix information for the d+d and d+t reactions in this more correct formulation, we have calculated rates for a variety of screened Coulomb potentials. The fusion rate calculations are presented as a function of the screening radius at fixed relative energy, and as a function of relative energy at fixed screening radius. They are compared with calculations made using the standard expression above.

MOLECULAR DYNAMICS SIMULATION OF $PD_{1.1}$: HOW CLOSE CAN DEUTERONS GET?

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Crucial to whether cold fusion can occur in Pd or similar metals is how close deuterons can get to one another in the hydride lattice, particularly if the concentration is above stoichiometry and/or there is large thermal agitation. To investigate these questions a molecular dynamics (MD) simulation has been done of $PdD_{1.1}$ and the distribution of D-D distances examined.

Pd-D potentials were used similar to those in previous MD simulations of hydrogen diffusion. They were modified slightly to allow investigation of cases both where the tetrahedral (t) site was stable and unstable. The screening length was taken as $a_0/2$ (a_0 = Bohr radius) so as to be highly optimistic about a weakened repulsion allowing for close D-D distances. Simulations were done at temperatures of 300 K and 1300 K.

In no case were distances shorter than 0.7 Å found. Thus no evidence was found for D-D separations significantly less than in molecular D_2 (0.74 Å). The fact that a fair number of distances less than 1.5 Å, considerably shorter than the equilibrium 2.8 Å below stoichiometry, are seen may, however, have implications for other aspects of hydrogen in metals.

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Conditions Leading to the Production of Cold Fusion Neutrons

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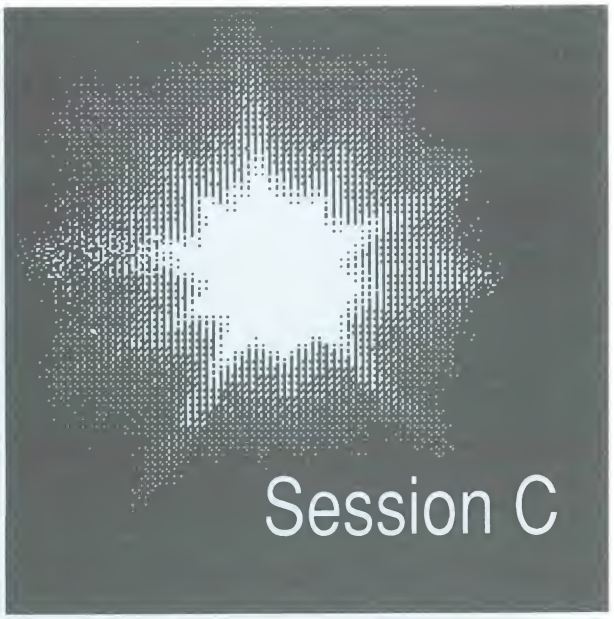
We have examined the conditions that must be attained within the metallic lattice in order to achieve $d + d \rightarrow {}^3\mathrm{He}{+}n$ thermonuclear fusion rates as observed by Jones *et al*, supposing that the so-called 'cold' fusion is occurring in small pockets of deuterium under plasma conditions. We establish i) the relevant time scales governing the plasma formation process, ii) the influence the conduction band electrons have on the fusion rate, and iii) the temperatures, densities and plasma lifetimes required to explain the reported neutron rates. The particular mechanism we are considering as being responsible for the formation of pockets of plasma is the catastrophic collapse of microscopic cavities between the metallic crystals, caused by the sudden expansion of crystals under stress. This process may lead to the formation of high density and temperature plasmas for brief periods of time. We note that the presence of the metal's conduction band electrons plays a significant role, firstly by screening the $d-d$ interaction and thereby reducing the temperature required for fusion, and secondly by absorbing the electronic component of the produced $d^+ + e^-$ plasma. The work is still in progress and at this time it is not established that the proposed model is a viable mechanism for neutron production. However, one can propose several experimental procedures whereby the creation of plasma pockets by the above mechanism may be tested. These include: i) the correlation of neutrons bursts with the application of mechanical stress or ultrasound to the material, and to the presence of micro-quakes which may be detected within the sample; ii) by initially preparing the metal sample in different ways so as to increase the amount of internal stress, such as by casting and cooling the metal very rapidly or by tempering; and iii) by combining the hydride with impurities that have different thermal expansion coefficients or which expand differently under hydridization. The plasma conditions that may exist could be probed by comparing different fusion reaction rates such as $p + d \rightarrow {}^3\mathrm{He}{+}\gamma$, $d + d \rightarrow {}^3\mathrm{He}{+}n$ and $d + t \rightarrow {}^4\mathrm{He}{+}n$.



COLD NUCLEAR FUSION IN CONDENSED MATTER: RECENT RESULTS AND OPEN QUESTIONS

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We have observed clear signatures for neutron emission during deuteron infusion into metals, implying the occurrence at low rates of nuclear fusion in condensed matter near room temperature. The cold fusion phenomenon has been demonstrated in collaborative experiments at Brigham Young University <1>, at the Gran Sasso Laboratory in Italy, and at the Los Alamos National Laboratory. We have shown that cold fusion can be induced in metals using both electrochemical and variational temperature/pressure means to generate non-equilibrium conditions <1>. Observed average neutron emission rates are approximately 0.04-0.4 n/s.

Current efforts focus on trying to understand and control the cold fusion phenomenon. In particular, we wish to understand the correlation of fusion yields with parameters such as hydrogen/metal ion ratio, pressure (induced, for example, by electric fields or gas pressure or mechanical pressure), temperature variations, hydride phase changes, and surface conditions (e.g., a palladium coating on titanium). We want to know if the fusion arises due to confinement of the deuterons in the lattice (piezonuclear fusion), or rather from 'microscopic hot fusion' accompanying strong electric fields at propagating cracks in the hydride. The latter interpretation would imply neutron emission in bursts.<2> Our experiments show clear evidence for emission of neutrons in bursts of less than 200 μs, although random (continuous) neutron emissions were also observed. Experiments now underway to compare the d-d, p-d, and d-t fusion rates will be important to an accurate description of the new phenomenon.

We should also consider the implications of this discovery. Although energy applications now appear extremely unlikely, cold fusion at enhanced rates could serve as a useful source of monoenergetic neutrons. Certainly, condensed-matter fusion provides a novel probe of extreme conditions in metal-hydrogen systems. Careful scrutiny of the effect could also increase our understanding of heat and helium-3 generation in the earth and other planets, and even in cooler regions of the stars.<1> The discovery of cold fusion may significantly impact our view of nature.

<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," Nature, 338: 737-740 (April 27, 1989).

<2> J. S. Cohen and J. D. Davies, "The cold fusion family," Nature 338: 705-707 (April 27, 1989).

EXPERIMENTAL EVIDENCE FOR COLD NUCLEAR FUSION

IN A MEASUREMENT UNDER THE GRAN SASSO MASSIF

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We have observed the emission of 2.45 MeV neutrons following the electrolytic infusion of deuterons into titanium electrodes in a replication of experiments performed at Brigham Young University.<1> The present results were obtained using neutron-gamma discriminating proton-recoil detectors at the Gran Sasso Laboratory. The observed neutron emission rate is comparable to that reported by Jones and collaborators. The observation of cold nuclear fusion under the Gran Sasso Massif where cosmic-ray intensities are $\sim 10^{-6}$ of sea-level values rules out the possibility that the observed neutron signal could be due to cosmic-ray muons or to cosmic-ray-induced neutrons <2>.

<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," **Nature 338**: 737-740 (April 27, 1989).

<2> J. M. Carpenter; A. J. McCevoy and C. T. D. O'Sullivan, in "Cold fusion: what's going on?" **Nature 338**: 711-712 (April 27, 1989).

THE MEASUREMENT OF NEUTRON EMISSION FROM Ti PLUS D_2 GAS

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We have measured neutron emissions from cylinders of pressurized D_2 gas mixed with various forms of Ti metal chips and sponge. For some of the cases, the Ti was coated with a surface layer of Pd. The gas pressure ranged from 20 atm to 50 atm, and the Ti loadings ranged from 30 g to 200 g.

The neutrons were measured using a high efficiency (34%) cavity-type detector containing 18 ^{3}He tubes. Random neutron emissions were observed as well as time-correlated neutron bursts. The time spread in an individual burst was less than 200 μs.

The neutron emission was observed after the cylinder had cooled in liquid nitrogen temperature and was warming to room temperature. The bursts occurred about 40 minutes into the warm-up phase, and the random emission occurred for at least 12 hours after the sample reached room temperature. This cycle could only be repeated two or three times before neutron emission ceased.

The neutron emission rates were very low and the 12-hour random emission rate was 0.05-0.2 n/s. However, this yield was still 11σ above the background. The instantaneous neutron bursts were more dramatic with yields several orders of magnitude above the coincidence background rates.

NEUTRON EMISSION FROM A TITANIUM-DEUTERIUM SYSTEM

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UPPER LIMITS ON EMISSION RATES OF NEUTRONS AND GAMMA-RAYS FROM "COLD FUSION" IN DEUTERIDED METALS*

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ABSTRACT

A search for neutrons and gamma-rays emitted in "cold fusion" in electrolytically deuterided metals was carried out with a very low background and a sensitive neutron detection system, composed of an array of six liquid-scintillator neutron counters operating in coincidence, with total efficiency of ~1%. Pulse shape, pulse height and time of flight were measured for scattered neutrons. Gamma-rays were detected in two large (12.5 cm) NaI(Tl) detectors, with total efficiency of 0.1% at 5.5 MeV. The detection system was shielded from background radiation and two large area cosmic-ray veto counters were utilized. Up to four electrochemical cells, similar to the ones used by Fleischmann, Pons and Hawkins (FPH) and by Jones et al., ran concurrently, with Pd or cold worked Ti rods as cathodes. The Pd electrodes were cold worked or annealed in vacuum or argon, one electrode was predeuterided and various surface treatments were carried out. The metals were electrochemically charged with deuterium in heavy water (97.5% or 99.8% D_2O) electrolytes containing LiOD or a variety of salts. Ti alloy powder deuterided at room temperature and high pressure was also used for comparison. No statistically significant deviation from the background was observed in either gamma-ray or neutron detectors, over three weeks. Using our neutron detector system we estimate (with 98% confidence) the rate of "cold fusion" of d + d in our Pd and Ti samples to be smaller than the order of 10^{-25} fusions/atom pair/sec (3σ limit), and the gamma ray data yield for (the faster) p + d fusion rate, a limit of the order of 10^{-22} fusions/atom pair/sec (3σ limit). The estimated neutron flux in our experiment is a factor of 50-100 smaller than that reported by Jones et al. and some million times smaller than that reported by FPH. We suggest that the FPH quoted neutron flux is in error, and the rate of vetoed cosmic ray induced neutron events, in our data, suggests the observation of Jones et al. to be cosmic muon induced events. An attempt to initiate "cold fusion" with 5 MeV alpha particles produced no measurable effect.

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LACK OF NEUTRON AND GAMMA RADIATION FROM PPPL's COLD FUSION EXPERIMENTS†

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We have tried to reproduce the various 'cold fusion' experiments(1,2) along with some variations to their basic schemes. To date, we have not seen evidence from any of our experiments for the production of either neutrons or gamma rays at rates above the background. Experiments performed include: (i) electrolysis in a pure D_2O cell with 1 molar LiOD (or LiOH) solution and various palladium cathodes at current densities up to 0.6 amperes/cm^2; (ii) electrolysis in a 50-50% D_2O-H_2O cell with a graded drawn Pd wire (or cast Pd sphere) cathode at current density up to 0.5 amperes/cm^2; (iii) thermal and pressure cycling of various high-pressure D_2 gas-loaded Ti turnings, and Ti powders, a Nb bar, alumina, quartz, and feldspar mixtures, etc..

For all the experiments, neutrons were measured with BF_3 proportional counters and gamma rays with NaI scintillation detectors, but at different times and with separate test stations. The neutron monitoring station was shielded with a polyethylene moderator and cadmium absorber, and the background count rate was found to be highly variable, ranging from 5 counts/hr to 30 counts/hr. The neutron detection efficiency was determined with a ^{252}Cf source to be 1% for experiments (i) and (ii) and 0.1% , 0.3% , or 1% for experiment (iii), depending on configuration. The gamma-ray station employed a NaI scintillator-photomultiplier closely coupled to the electrolysis cell. The detector was surrounded by a cylindrical annulus of NaI filled with 6 photomultipliers. The central and surrounding detectors were operated in anti-coincidence mode to minimize spurious signals from external sources. The experiment was surrounded by lead shielding to further reduce background; the background rate was 5 - 15 counts/hr in a 1- MeV wide window around the 5.5 MeV region of interest. The gamma detector energy calibration was determined with ^{60}Co and ^{137}Ce sources. We thus claim that our neutron counting apparatus can continuously resolve a neutron source strength of 1 neutron/sec and our gamma counting apparatus is capable of resolving a gamma source strength of 1 photon/sec. However, our apparatus could not detect neutrons as low as the level of Jones et al(3).

We have considered the possible proton- and deuteron-induced nuclear reactions with the various isotopes present in the electrolysis apparatus. We note that there are no bound excited states in ^4He, and only 3 unbound excited states lie below the d + d reaction threshold. The width of the lowest lying excited state (at 19.8 MeV) is 0.27 MeV, the higher excited states are broader and overlap strongly, and thus, one would expect the nearly prompt (10^{-20} sec) decay by particle emission from the compound ^4He nuclei rather than an electromagnetic mode of decay (see, for example Ref. 4). Therefore, in our theoretical efforts, only two mechanisms for 'cold fusion' are considered: (i) tunneling through coulomb barrier by 'cold' deuterons, and (ii) cold target bombardment by deuterons accelerated in bursts(5). The fusion rates for tunneling in p-D, D-D, and D-T molecules have been computed. The dependence of fusion rates on electron mass and temperature will be presented. This suggests that if the experiments of Ref. 1, 2, 3, and 5 were repeated with mixtures of hydrides and deuterides, the relative importance of quantum-mechanical tunneling vs. simple cold target bombardment would be determined.

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† This work is supported by the U.S. DoE contract No. DE-AC02-76-CHO-3073.

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AN ATTEMPT TO MEASURE CHARACTERISTIC X-RAYS FROM COLD FUSION

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We have carried out tests using an electrolytic cell modeled after the Pons-Fleischmann descriptions, but with several modifications to allow the detection of characteristic X-rays emitted from the palladium electrode. In virtually any fusion reaction that could be postulated as taking place within the electrode, the energetic charged particles formed in the reaction would inevitably excite 21 keV characteristic K X-ray from palladium. If the structures and water of the cell do not absorb these X-rays before they emerge, then an external detector can have nearly 100% intrinsic efficiency for their detection.

A 1.5 by 1.5 cm palladium foil of 0.5 mm thickness was located within several millimeters of a thin nylon window fitted into the side of the glass cell. Two additional platinum electrodes were mounted at either side of the cell, and 0.1 M LiOD electrolyte in heavy water filled its internal volume. An electrolytic current ranging from 7 to 48 mA was sustained over a period of 7 days. The palladium electrode was observed to distort somewhat over this period, consistent with the hypothesis that substantial deuterium loading of the metal took place.

A germanium detector with thin endwindow was placed within several millimeters of the cell window outer surface throughout the experiment. Background data were obtained by inserting a 0.2 mm thick copper disk in front of the detector, of sufficient size to shadow the palladium sample. In separate measurements, a radioisotope source of X-rays was used to calibrate the detector energy scale and to verify the transmission properties of the cell components.

Over the period of time during which current was flowing in the cell, and for one day thereafter, no statistically significant differences were observed in data taken with and without the copper disk in place. We therefore conclude that no measurable characteristic X-rays were generated in the palladium over the period of the experiment.

Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells*

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A controversy exists concerning the analysis of the heat observed from palladium-deuterium electrochemical cells. This is partially due to the fact that calorimetry can only measure the enthalpy (heat) of the reaction; whereas, the energy supplied to the Pd-D electrochemical cells reflects a free energy of the reactions occurring within the cell. The fundamental interrelationships among the diverse concepts of 1) calorimetrically measured heat, 2) the cell potential, 3) the thermoneutral potential, 4) electrolytic and galvanic electrochemical reactions, 5) the endothermic cooling effect of the heavy water electrolysis, 6) the energy returned from any subsequent gas recombination, and 7) the internal pressure, fugacity, and thermodynamic activity of deuterium in the palladium will be presented.

The experimental effort at Sandia National Laboratories includes the calibration of a unique calorimeter, which operates on the principle of accurate measurements of the vaporization rate of liquid freon which completely surrounds the Pd-D cell. Unlike other recent calorimeter experiments on the Pd-D system, this calorimeter does not depend on the measurement of temperature within the cell and, therefore, avoids the present objections of possible temperature gradients (due to poor mixing within the cell) causing the reported excess heats.

The freon vaporization calorimeter has been assembled and initial electrical calibrations show a measured power resolution of 0.1 watts. Measurement of cell temperature will also be performed to give an independent measure of cell heat output. We installed He^3 neutron detectors around the cell to allow one of the first simultaneous sensitive radiation with calorimetry experiments. We will report on results of this combined calorimetry/radiation experiment at the time of the workshop presentation.

The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations*

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The primary assertion of Profs. Fleischmann and Pons in their recent experiments with electrochemical loading of deuterium in palladium[1] is that more energy is produced than is consumed in the process. Their attribution of this excess energy to nuclear fusion is derived from a power balance calculation based ultimately on Newton's Law of Cooling which may not be directly applicable in their experimental situation. They use a submerged resistor to heat the electrolyte solution and assume a constant heat transfer coefficient which in turn is used to calculate the energy loss rate, $k_T\Delta T$, to the surrounding environment.[2] Since the sum of this calculated loss rate and the chemical potential increase from electrolysis is greater than the electrical power input, they require the additional energy source. However, total heat loss (especially from evacuated Dewar cells) may be dominated by evaporation of electrolyte which increases exponentially with temperature. In many everyday situations, evaporation is limited to small amounts by vapor diffusion rates. In this experiment, the bubbles of electrolyzed D_2O are saturated with water vapor and also serve to enhance convection of water vapor from the surface. Thus, during the calibration period at higher temperature, they may have overestimated the heat transfer coefficient applicable at the lower operating temperature. Even though the change in temperature for the calibration run described in ref. 2 was only 1.55 K, the corresponding water vapor partial pressure change, ΔP, which drives evaporation, is large. The key to the difficulty is the nonlinearity of the heat loss process with temperature variation, i.e., k_T is not constant. Other nonlinear chemical reactions involving heat loss from the cell could also contribute to the perceived energy balance discrepancy. If evaporation dominates, energy loss can vary as $k_p\Delta P$, where k_p is a constant. In this paper, calculations are presented to support the plausibility of this argument which negates the reason to postulate significant levels of fusion power.

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ABSTRACT

SEVEN CHEMICAL EXPLANATIONS OF THE FLEISCHMANN-PONS EFFECT

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Seven chemical explanations are stated and quantitatively analyzed. (a) The D_2O solution drops below the top of the electrode, and it pumps H out to an O contact at the Pd - gas interphase. (b) The same, but the situation described occurs inside the electrolyte with O_2 in bubble form from the anode, impelled sporadically against the cathode.

(c) $D_2 + O_2$ recombination in the gas phase.

(d) The $\alpha \rightarrow \beta$ transition is incomplete and continues for > 100 hours.

(e) The H/Pd ratio grows 0.7 - 1.25 over ~100 hours.

(f) Pd D_2 forms and dissociates sometimes explosively.

(g) Li alloys with Pd and this provides a heat of reaction.

The watts provided by these effects are compared with the heat reported from the Pd-D_2 system at high overpotential.

EVIDENCE AGAINST CONDENSED MATTER FUSION INDUCED BY COSMIC-RAY MUONS

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If has recently been proposed that the cosmic ray muons might catalyze d-d fusion in condensed matter[1], offering a possible origin for claims of observations of fusion neutrons from deuterated Pd or Ti. In order to test this hypothesis, we have studied the behavior of accelerator-produced negative muons in Pd(D).

The experiment was carried out at the pulsed muon facility of UT-MSL/KEK by measuring the following muon-induced envents ; a) timing of decay electrons to see the relative fraction of muons stopping in D versus Pd by a lifetime method; b) energy and timing of neutrons with n-γ discrimination to see fusion neutrons ; c) energy and timing of X-rays to see (μ^3He) events associated with (ddμ) fusion if it exists. All the experimental arrangements employed here were the same as those used for the recent successful experiments on a direct observation of alpha-sticking phenomena in liquid and high T_2 concentration D_2/T_2 mixtures by the X-ray method[2].

The Pd(D) samples used were a) a 5mm diameter Pd rod with 10 days D loading ; b) a 3mm thick Pd plate with 60% D loading; c) a 1mm thick Pd plate in D_2O with electrolysis in situ. As a control, we used Pd samples without D.

So far, no differences were observed between Pd and Pd(D) in all the above observables for these 3 systems, placing a limit on atomic capture ratio for D to Pd (below 5%) and on (ddμ) fusion rates in Pd(D) (below $0.1/\mu^-$). The obtained result provides evidence against the extraordinarily enhanced fusion rates assumed in the proposal[1].

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Abstract to be submitted to the Workshop on Cold Fusion Phenomena,
May 23-25, 1989, Santa Fe, New Mexico

CALORIMETRIC MEASUREMENTS ON ELECTROCHEMICAL CELLS WITH Pd-D AND Pd-H CATHODES

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Introduction

The purpose of these experiments was to verify the results provided by M. Fleischmann and S. Pons, University of Utah [1]; they were not designed to verify the results of S.E. Jones [2]. The experiments sought to determine the presence of "excess heat"; experiments will also be undertaken to determine the presence of neutrons.

Technical Approach

Two series of experiments have been performed: (1) differential comparison of temperature deviations between identical light- and heavy-water electrochemical cells and (2) calorimetric measurements of heavy-water cells under varying electrochemical conditions.

In the first series of experiments, the temperature difference of identically built and operated (current density and operational times) Pd-H/LiOH-saturated H_2O/Pt and Pd-D/LiOD-saturated D_2O/Pt cells was observed. We anticipated that both cells would operate at identical temperatures but that the D_2O cell would become much hotter after the onset of cold fusion. However, we found it difficult to provide identical conditions in both cells. At identical current density, the operating cell voltage of the D_2O cell (therefore, also the temperature) was higher. When the current density and the voltage were made identical, the H_2O cell became warmer (ΔT=0.8 K). We concluded that this type of experiment was too ambiguous and not suitable for evaluating the levels of heat and the special effects of deuterium now being reported.

In the second series of experiments, two Pd-D/LiOD-saturated D_2O/Pt cells in constant-heat-loss calorimeters were operated to detect "excess heat" evolution. Excess heat is defined in this report as a heat output from the cell that is higher than the heat equivalent of the electrical input [(cell voltage minus 1.53 V) multiplied by cell current]. The cathodes in both kinds of experiments were wrought palladium 5.0 cm in length and 6.3 mm in diameter. Under a series of well-defined electrochemical conditions (times and electrolyte additives) that were expected to increase the D/Pd ratio, we examined the various contributors of the electrical and heat inputs and outputs at various current densities (15-500 mA/cm^2). In addition, we calculated the mass and heat balances for the duration of the experiment to evaluate short- and long-range system transients. Thus far we have not found any excess heat within the sensitivity (0.13 W, 0.082 W/cm^3 of Pd or 0.013 W/cm^2 of Pd) and precision of the calorimeter. For now, the experiments are continuing. A detailed description of the experimental apparatus and of the analysis of the measured data will be presented.

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Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis.

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This talk will focus on our preliminary results on calorimetric studies on water and deuterium oxide electrolysis using Pt or Pd cathodes with LiOH(D) and NaF as the supporting electrolytes. In some cases, sulfur was added as an intentional poisoning agent. The Pt or Pd rods were 1 to 1.5 mm in diameter. Radiation levels were monitored by neutron activation of copper or silver metal. These studies were prompted by a recent note on electrochemically induced nuclear fusion (1).

A deuterium oxide solution, containing NaF and the Pd cathode poisoned by sulfur was electrolyzed for 14 days. In terms of excess heat, the results appeared to be negative. Next, matched cells, with a Pd cathode in one and a Pt cathode in the other were tested for temperature differences in deuterium oxide containing 0.1M LiOD. After one week of electrolysis (100 mA/cm^2), no unexplained temperature differences between these cells were observed. However, this experiment is ongoing, and any future results will be given.

A comparison of the steady state heat evolution between water and deuterium oxide (LiOH(D) electrolyte, Pd cathode) indicated that the deuterium oxide cell was producing more heat than the water cell. The Newton cooling constants, 0.0538 J/s^oC (H2O cell) and 0.0541 J/s^oC (D2O cell) were determined by resistance heating in well stirred solutions. During the electrolysis (100 mA/cm^2), no temperature changes were noted as a function of the thermometer placement, and thus, the cells were not stirred mechanically. All trials resulted in an excess calculated heat, with the D2O always producing more excess than the water cells. For example, in one trial the excess heats were 0.201 and 0.223 J/s for the water and D2O cells, respectively. We attribute these observations, wholly or in part, to recombination of the gases (2). Further refinements on these cells are being made and the results will be shown and discussed.

Finally, remote monitoring of a scaled-up cell, in hopes of recording the Pd ignition event (1), is being planned. Progress towards this effort will be described.

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PAC STUDIES OF ELECTROLYTICALLY CHARGED METAL CATHODES *[1]*

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Cold nuclear fusion reactions might occur at special, "active" sites in the cathode, such as in lattice vacancies. We have investigated hydrogen (H) interactions with vacancies in metals on an atomic scale, using perturbed γ-γ angular correlations (PAC) of ^{111}In probes.*[2,3]* Our approach has been to trap diffusing H atoms in pre-existing probe-vacancy complexes. H trapping is detected microscopically by changes in the hyperfine interactions signals. Binding enthalpies of ~0.5 eV and occupation numbers of H in the complexes have been deduced from changes of signal amplitudes during charging and annealing. Some results are as follows:
(1) Divacancy and trivacancy complexes in Ni*[2]* and Pt*[3]* are rapidly decorated by H atoms after charging for a few minutes at 20 mA/cm^2 in 0.1 M H_2SO_4.
(2) NiH can be formed by charging Ni at ~200 mA/cm^2, whereas it is only formed under gas pressures in excess of 6 kbar.
(3) Li was the only common cation in electrolytes used by Fleischmann and Pons and by Jones et al. Because its radius is small, Li may diffuse interstitially in the cathode, like H. Using a Pt cathode and 1.0 M LiOH electrolyte, the pH was observed to drop from 13.3 to 9.4 after 24 hours at ~20 mA/cm^2, demonstrating that most Li deposited onto and/or diffused into the electrode. Experiments are in progress to detect Li diffusion in the lattice by observation of new signals corresponding to Li-decorated vacancy complexes.

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INTERACTION OF DEUTERIUM WITH LATTICE DEFECTS IN PALLADIUM

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ABSTRACT

The interaction of ion-implanted deuterium (D) with lattice defects and He bubbles/voids in single crystals of palladium (Pd) was investigated by ion-beam-analysis techniques. Experimental data for the amount of D retained during linear-ramp annealing were analyzed using transport theory to obtain trap strengths. Small He bubbles/voids were found to trap D with a binding enthalpy of 0.31 eV relative to the solution site, whereas implantation damage trapped D with three different binding enthalpies, 0.31 eV, 0.23 eV, and 0.15 eV, attributed respectively to vacancy clusters, monovacancies with low D occupancy, and monovacancies with high D occupancy. Each Pd vacancy can accomodate up to six D atoms. The lattice location of D trapped to monovacancies is obtained by the channeling technique, following anneals at various temperatures. At low temperatures, T~25 K, D occupies the octahedral (O_h) interstitial site which is the solution site for D in fcc metals. At T~100 K, D becomes trapped by vacancies, and at 200 K, just before the depopulation from the vacancy is initiated, 60% of the D is at a near-tetrahedral site, in which the remaining 40% is deposited 0.3 Å from the O_h site towards the vacancy. The experimental results are compared with the theoretical prediction of the effective-medium theory.

SEARCH FOR COLD FUSION IN SUPERSTOICHIOMETRIC PALLADIUM DEUTERIDE USING ION IMPLANTATION

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Deuterium-deuterium distances in D-charged Pd are expected to be reduced for D-to-metal atom ratios above one, since excess D remains after filling of the octahedral interstitial solution sites. Such atom ratios are usually not achieved by electrochemical or gas-phase charging, but D ion-implantation at a temperature of 35 K was previously found to yield compositions up to D/Pd = 1.3. We have implanted similar high fluences of D into Pd at 40 K and an energy of 10 keV, and have used a solid-state detector to search for high-energy D and T particles from the D-D nuclear reaction. Copious charged particles of the appropriate energies were produced by the impinging D beam, thereby verifying the operation of the detection system and permitting the buildup of the D concentration to be monitored. After the beam was turned off, however, fusion events were not detected during about 9 hours of counting at 40 K. We estimate an upper bound on the reaction rate of 10^{-21} events/D/s. Similarly negative results were obtained for D-implanted Zr.

During warmup of D-implanted Pd, the D/Pd atom ratio was monitored by measuring the yields of energetic H and T induced by bombardment with 30-keV D. The D concentration decreased in distinct stages at 120 and 220 K. The first stage is attributed to rapid diffusion of the excess D in the superstoichiometric hydride, and its occurrence supports the existence of a D/Pd ratio above one; the second stage is then ascribed to D release by conventional diffusion in the normal hydride phase. Theoretical consideration of the respective diffusion processes yields relative rates consistent with the temperature separation of the two stages.

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Tritium Enrichment in the Electrolysis of D_2O

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The tritium content of heavy water manufactured by the GS process (H_2S - H_2O dual temperature exchange) is calculated as a function of the tritium content of the feed to the heavy water plant. Fresh heavy water has a tritium activity of 68 dpm $(cc\ D_2O)^{-1}(TU)^{-1}$. The gross tritium enrichment into heavy water during electrolysis is calculated from the theory of relative enrichment[1] and the experimental data of Ostlund and Werner [2] as a function of the T/D separation factor. For separation factors in the range $1.6 < k_D/k_T < 2.2$, the overall enrichment increases from 1.4 to 5.1 as the fraction of water electrolyzed increases from 0.6 to 0.95. Implications with respect to cold fusion experiments will be discussed.

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Nuclear Fusion from Crack-Generated Particle Acceleration

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We propose a conventional interpretation for the neutron production in electrochemical ("cold" fusion) experiments[1,2]. We suggest that electrostatic acceleration of deuterons results from internal cracks in the highly-stressed, deuterium-loaded metal lattices. After sufficient internal stresses have accumulated, cracks may propagate through the metal. The lattice surfaces, on either side of the crack, are left with unbalanced electrical charge. As the crack grows, the charged surfaces separate while maintaining constant charge, thereby increasing the voltage across the crack gap, as $V = 10^9 \eta d$ eV, here η is the number of imbalanced charges per square lattice constant (16 square angstroms for palladium), and d is the gap separation. With $\eta = 0.1$, and $d = 10^{-5}$ cm, $V = 10^3$ eV, or with $d = 10^{-4}$ cm, $V = 10^4$ eV. Stray deuterons falling across the gap may then acquire energy sufficient to produce conventional d-d nuclear reactions at rates comparable to those apparently observed in some cold fusion experiments [1,2]. The surface charge must be maintained for at least the deuteron transit time across the gap, roughly a few picoseconds. A number of effects, near the tip, may allow for this relatively long relaxation time.

The electrostatic stored energy in the crack electrostatic fields is easily calculated to be about $E = 10^5 \eta^2 d/2$ joules/cm^2. If the cracks are created and then electrostatic energy is discharged from tens of square centimeters per second, then watts of electrical power may be released and appear as excess heat.

Finally, lattice fracture, in strongly shocked, lithium deuteride, has recently been proposed by Klyuev [3], et. al., as the mechanism responsible for their observed d-d neutron generation at low levels.

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Search for 0.8 MeV ^{3}He Nuclei Emitted from Pd and Ti Exposed to High Pressure D_2

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To look for evidence of cold fusion leading to n + ^{3}He, we have exposed track-recording plastic films in direct contact with Pd and Ti sheets inside a cell containing D_2 at pressures up to ~15 bars. A portion of each film not in contact with metal served to measure backgrounds due to alpha decay of radon and to cosmic ray-induced spallation of C and O in the plastic films. We have cycled between 77 K and 300 K and between 1 and 15 bars, and also reduced the pressure with a forepump as done at Frascati. For a Pd sample with atom fraction D/Pd = 0.5 (measured by weight gain) the track density due to ^{3}He ions emerging from the surface was <20 cm^{-2}; results for Pd loaded to D/Pd = 0.8 by electrolysis and for Ti loaded with D will be reported. The corresponding limit on the number of neutrons, ~4 x 10^4 per gm, is far lower than the numbers reported in the two Frascati experiments with Ti (~3 x 10^5 per gm and ~3 x 10^6 per gm) and in the Genoa experiment with Pd (~6 x 10^7 per gm). We calculate that lattice damage cannot explain the non-reproducibility of the Italian experiments.

IN SEARCH OF NUCLEAR FUSION IN ELECTROLYTIC CELLS AND METAL/GAS SYSTEMS. D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden, W.G. Cross, A. Arjona, A.M. Lone, D.C. Tennant and W.J.L. Buyers, Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited, Chalk River, Ont., Canada K0J 1J0, and K.W. Chambers, A.K. McIlwain, E.M. Attas and R. Dutton, Whiteshell Nuclear Research Establishment, Atomic Energy of Canada Limited, Pinawa, Man., Canada R0E 1L0. A variety of electrochemical cells having palladium cathodes in the form of wires, tubes, foils and rods have been used to electrolyse heavy water containing 0.1 $mol.dm^{-3}$ LiOH, 0.1 $mol.dm^{-3}$ LiOD or 0.50 $mol.dm^{-3}$ D_3PO_4. Current densities of up to 140 $mA.cm^{-2}$ were used. The mass of the palladium cathodes covered the range from 1 to 40 grams and the surface area varied from 8 to 140 cm^2. Neutron detection systems with low constant backgrounds were used to search for the presence of a neutron flux during electrolysis. These included moderated ^3He- and $^{10}BF_3$-based detectors. After running some of the cells for times up to 28 days no neutron flux above background could be detected. No enrichment of the electrolytes in tritium was evident after correction for evaporative losses. Chemical analysis of one of the cathodes after 25 days of near continuous electrolysis indicated that the average bulk composition was $PdD_{0.7}$ with the ratio of deuterium over palladium remaining constant to a depth of at least 20 μm. Experiments were also performed with the titanium metal/deuterium gas system. These consisted in exposing titanium metal to a deuterium gas pressure of 40 atm, lowering the temperature to -196°C, releasing the pressure and gradually warming the titanium to room temperature. No neutron flux above background was observed during these experiments.

Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes.

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Results of experiments intended to reproduce the excess heat and neutron emission from electrochemical cells[1] are presented. Radiation emission and power balance measurements were carried out on a set of electrochemical cells consisting of Pd cathodes, Pt anodes, and D_2O/LiOD or H_2O/LiOH electrolytes. The first phase of this experiment was aimed at determining gross excess heating effects (> 30% of applied power, calorimetry based on observation of temperature fluctuations for constant power input), or unusual neutron or X-ray emission, from cells with 6.4 mm diameter Pd rods operated for >45 days. The second phase of the experiment featured improved accuracy and data aquisition in experiments with 1 and 3 mm diameter Pd rods. Results of calorimetry (power balance measured in a constant temperature calorimeter), controlled to ± 15 mW, and calibrated neutron and X-ray measurements will be presented. In addition, we have measured ^3T levels in all cell electrolyte solutions before and after electrolysis, and we have analyzed for ^4He in effluent gas from cells containing 1 mm diameter Pd cathodes. We anticipate presentation of results regarding the presence of ^4He which may be present (trapped) within the Pd lattice.

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1. Fleischmann, M.; Pons, S.; Hawkins, M. *J. Electroanal. Chem.* **1989**, 261, 301.